OBJECTIVE ANALYSIS OF PRESSURE HEIGHT DATA FOR THE TROPICS

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ABSTRACT

A method for objectively analyzing the geopotential height field on a constant pressure surface using reported upper-air data is described. Special attention is given to the analysis in data sparse regions, in particular, the Tropics. Wind-height relationships are used to augment the reported data by extrapolation of the reported height values into the data voids. The augmented data are used in a least-squares process to generate a polynomial surface which is used as the initial guess in an iterative-correction routine. The resultant objective analysis is comparable to the subjective analysis produced by an experienced analyst. Comparative examples are presented in which the region of analysis encompasses the Caribbean Sea, Gulf of Mexico, and adjacent areas.

1. INTRODUCTION

The introduction of the high speed electronic computer and its subsequent use in routine numerical weather prediction (1) made it necessary to produce quickly accurate meteorological analyses of reported data as input to machine forecast programs, and (2) pointed to a possible solution of this problem through the use of the computer as the tool for objectively producing the required analyses in a fraction of the time required by conventional methods.

The initial investigation into objective analysis of meteorological parameters was performed by Panofsky [8]. He attempted to reproduce upper-level wind patterns and contour fields by least squares fitting of bivariate polynomials (of degree 3) to observations in localized areas. Wind reports were used as a constraint on the contour alignment and spacing.

Gilchrist and Cressman [5] also used polynomial fitting, but the fit was restricted to a small area surrounding each grid point. An interpolation polynomial of degree 2 was generated for each point. During an initial scan, these polynomials were dependent only on the data reports. Subsequent scans, which were necessary to fill in data voids, utilized previously interpolated grid values.

A method which does not rely on interpolation to obtain grid point values was developed by Bergthórsson and Döös [2]. This method is essentially the basis of all the so-called "correction" methods which have since been developed. A preliminary (guess) field, which may be the weighted sum of forecast and normal values, is initially specified at the mesh points. The guess values are used in conjunction with the observations to compute a first estimate of the grid-point values. Reported wind data are used under the geostrophic assumption to extrapolate a second estimate of the grid values; the gradient of the guess field about the grid point is used along with reported data to obtain a third estimate. The forecast and normal fields are then combined in a weighted sum with the three derived fields to obtain a final array of grid values. The weights are obtained statistically, and are a function of time, position, and distance from station to grid point.

The correction method was further developed by Cressman [3]. A first guess of the field to be analyzed is specified at the mesh points. In a series of scans over the grid, grid-point values are modified by a weighted mean of corrections based on reported data falling within a specified distance N from each grid point. The value of N is decreased with successive scans; the resulting field of the latest scan is taken as the new approximation. To eliminate discontinuities in the derived patterns, a smoothing function is applied to the grid values between the final correction scans.

Two recent investigations were concerned primarily with the analysis of data from tropical regions. Yanai [10], using a method basically the same as Cressman's, developed an analysis scheme for surface parameters and upper-level winds for the relatively data-sparse Caribbean region. Bedient and Vederman [1], employing similar techniques, analyzed the upper-air wind field for several levels over the tropical Pacific Ocean areas.

This report describes an objective analysis technique for the geopotential height fields on constant pressure surfaces. The primary concern here is the treatment of areas of sparse data coverage; the particular area of interest is the Caribbean Sea and adjacent subtropical regions.

2. METHOD OF ANALYSIS

The region of analysis considered in this report is shown by figure 1. Stations are concentrated on a line oriented NW–SE with the largest concentration on the mainland of the southeastern United States. The average distance between stations off the mainland is quite large. This is a typical feature of station distribution in oceanic and tropical regions. Only the boxed stations (fig. 1) report on a regular basis; therefore, at one observation time, the available data sample can be quite small. A grid spacing of 2° longitude (at 22.5° latitude on a Mercator projection, true at 22.5° latitude) was chosen so that synoptic scale features would be adequately resolved in the objective analysis. The procedure currently in use evolved through a series of experiments which are described below. Because of computer limitations the original area of interest (fig. 2) was smaller than that shown by figure 1.

The distribution of stations suggested that a "correction" technique would probably not work adequately without a good initial guess. Therefore, to obtain a guess field, a polynomial surface was fitted to the reported isobaric heights. The polynomial had to be of sufficiently high degree that the number of maxima and minima of the surface would be at least equal to the number of significant Highs and Lows which could be present in the height pattern.[1] Polynomials of degree 1, 2, and 3 are limited in this respect; hence, as a first attempt, a polynomial of degree 4 in the transformed space coordinates x ($\equiv$ latitude) and y ($\equiv$ longitude) was fitted by least-squares to the observed heights. The quantity minimized in the process was

$$Q=\sum_{k=1}^{S}(h_k-Z_k)^2 \tag{1}$$

where S is the number of height observations h_k

$$Z_k=\sum_{i,j} a_{ij}x_k^i y_k^j \tag{2}$$

[1] In order to avoid unrealistic analyses resulting from gross errors in the reported data, a machine program was coded which aids in eliminating obvious errors in the data reports. The program has built-in data validity checks which diagnose probable errors and allow for data correction. Geopotential heights are recomputed and wind and height data are presented at 50-mb. levels in the vertical, starting at 1000 mb. Upper-air wind reports (pibal, etc.) can be merged with the radiosonde report to give a more comprehensive wind sounding.

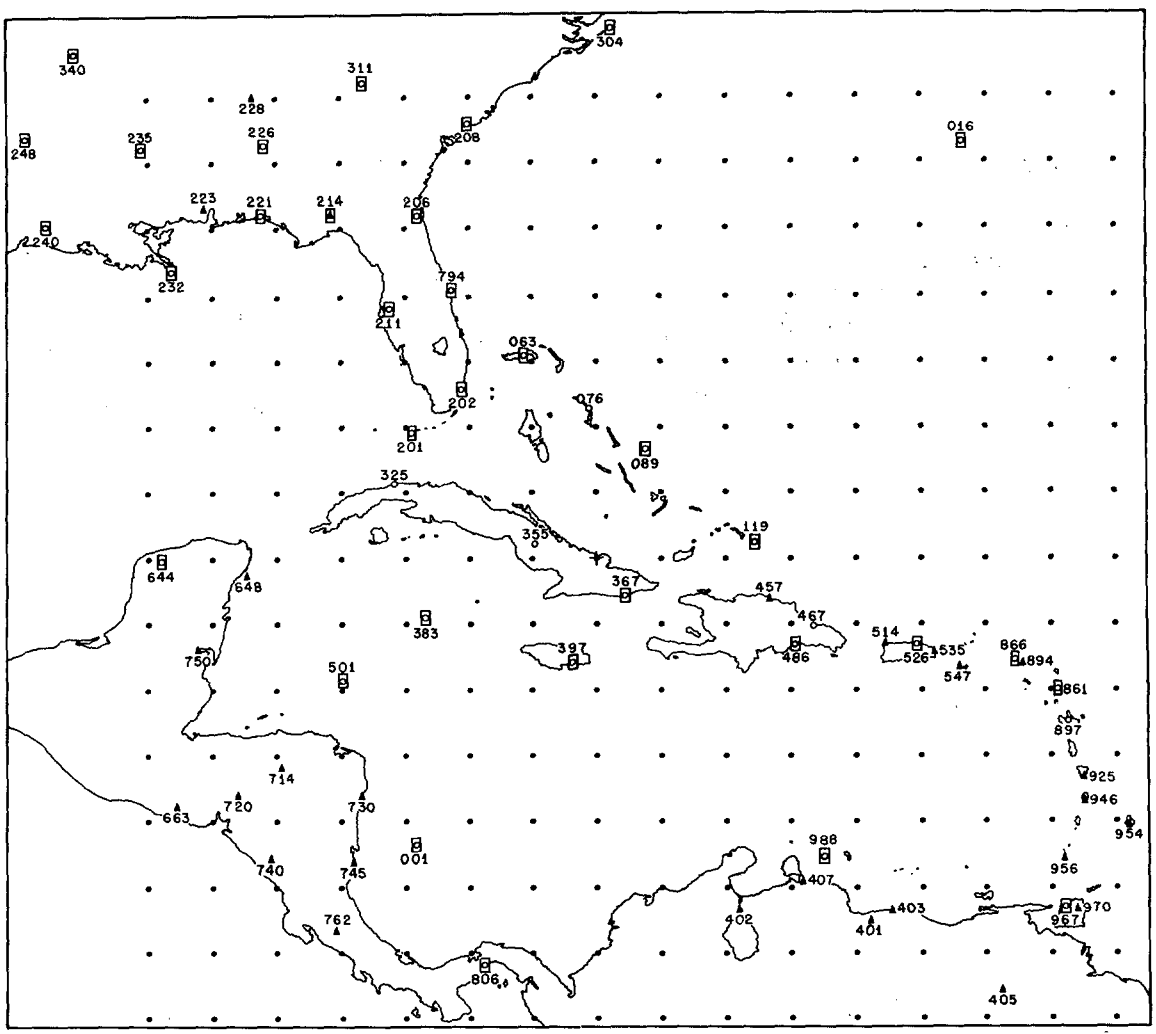


FIGURE 1.—Region of analysis and grid (15×16). Stations are given by their identification number. Open station circles denote radiosonde reporting stations; closed triangles denote upper-level wind reporting stations; and boxed-in station symbols signify stations which report on a regular basis.

$0 \leq i+j \leq n=4$, and x_k, y_k are the transformed space coordinates of the reporting station. The coordinate transformations are for a grid on a Mercator projection and are given by

$$x_k=3.80-0.050\lambda_k, \tag{3a}$$

$$y_k=2.860 \log_e\left(\frac{\tan (\pi/4+\phi_k/2)}{1.455}\right) \tag{3b}$$

where λ_k is the longitude and ϕ_k is the latitude of station k. Using these transformations, $|x_k|<1$, $|y_k|<1$ for all stations used in the procedure, and

$$(x=0, y=0) \equiv (76° \text{ W. long.}, 21° \text{ N. lat.})$$

As an initial test of the effectiveness of the fitting process, a polynomial surface of degree 4 was fitted to the latitude and longitude of 30 stations. The derived surfaces showed some departures from true latitude and longitude in the data-sparse regions (fig. 3); but, in general, the polynomial surfaces reproduced the grid and station latitudes and longitudes remarkably well (table 1). This result was anticipated in view of the simple behavior of the variables.[2]

Surfaces fitted to the observed height data were not as satisfactory. The lack of data in the southwestern and northeastern areas of the grid resulted in analyses which were meteorologically unreasonable (figs. 4a, 4b). In order to constrain the surfaces in these regions, sets of "control" data were added to the reported heights. These data were either climatological or forecast height values for selected points in the area of analysis. The points were located (see fig. 2) such that data voids would be partially filled and a height gradient normal to the boundary would be prescribed. The resulting analyses were meteorologically acceptable in a gross sense (fig. 4c).

After examination of the height data for a large number of synoptic time periods, it was evident that even though hydrostatically consistent heights were obtained by integration of the radiosonde data, certain stations consistently had height values which were not compatible with the height and wind fields specified by the data from surrounding stations. The height data for stations on the Florida Peninsula illustrate this rather clearly. Hodge and Harmantas [6] have shown that radiosonde sensing instruments of different manufacture give results which differ significantly in the upper levels of the troposphere. Systematic incompatibility of height data for contiguous stations could therefore result from the use of different sensing equipment, which is the case with the U.S. Weather Bureau and the military weather services. Also, a systematic error can be introduced by the use of nonstandard operational procedures. In order to eliminate

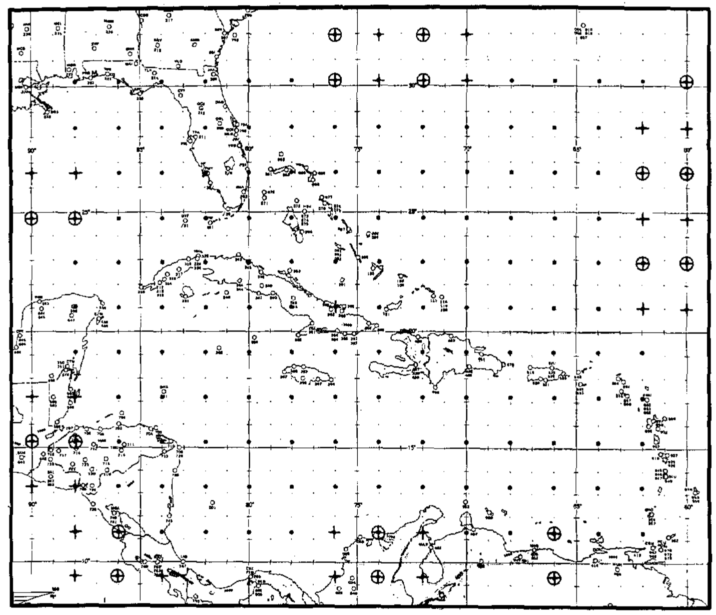


FIGURE 2.—The initial 11×14 objective analysis grid with the auxiliary data points ("control" points). The circled crossed points comprise the basic set of control points; the crossed points are additional control points.

gross horizontal deviations in the height data, a horizontal smoothing routine similar to that of Endlich and Mancuso [4] is used preliminary to the least-squares fitting process. The smoothing is basically a correction scheme. Only stations having a wind report are used in the smoothing; for each of these stations an adjusted height is computed based on the height and wind data of nearby stations.

Let H_i denote the height at the ith station which lies within a circle of radius R about station S. Then the height at station S is given by

$$H^*_{S_i}=H_i+\int_L \nabla H \cdot \boldsymbol{\delta}\mathbf{s} \tag{4}$$

where $-\nabla H$ is the gradient of H, and $\boldsymbol{\delta}\mathbf{s}=dx\mathbf{i}+dy\mathbf{j}$; the integration of the height gradient is over the straight-line path between stations i and S (fig. 5). The integral in equation (4) is evaluated numerically.

With the geostrophic assumption, the integral can be written

$$\Delta H^*=\frac{1}{g}\int_{x_i}^{x_s} fvdx-\frac{1}{g}\int_{y_i}^{y_s} fudy \tag{5}$$

where $f=2\omega \sin \phi$, u and v are the horizontal wind components, and g is the gravitational acceleration. The integrations are with respect to latitudinal and longitudinal earth distance. Since all computations are made relative to the specified grid, the earth distances are transformed into grid distances by the relationships

$$dX=\sigma^* m dx=\sigma^{-1}dx \tag{6a}$$

$$dY=\sigma^* m dy=\sigma^{-1}dy \tag{6b}$$

[2] When an orthogonal grid is overlaid on a Mercator projection the grid longitude is given by a linear function of longitude and the grid latitude can be approximated reasonably well by a quadratic function of latitude. Hence, an interpolation surface can be derived with a small number of data points.

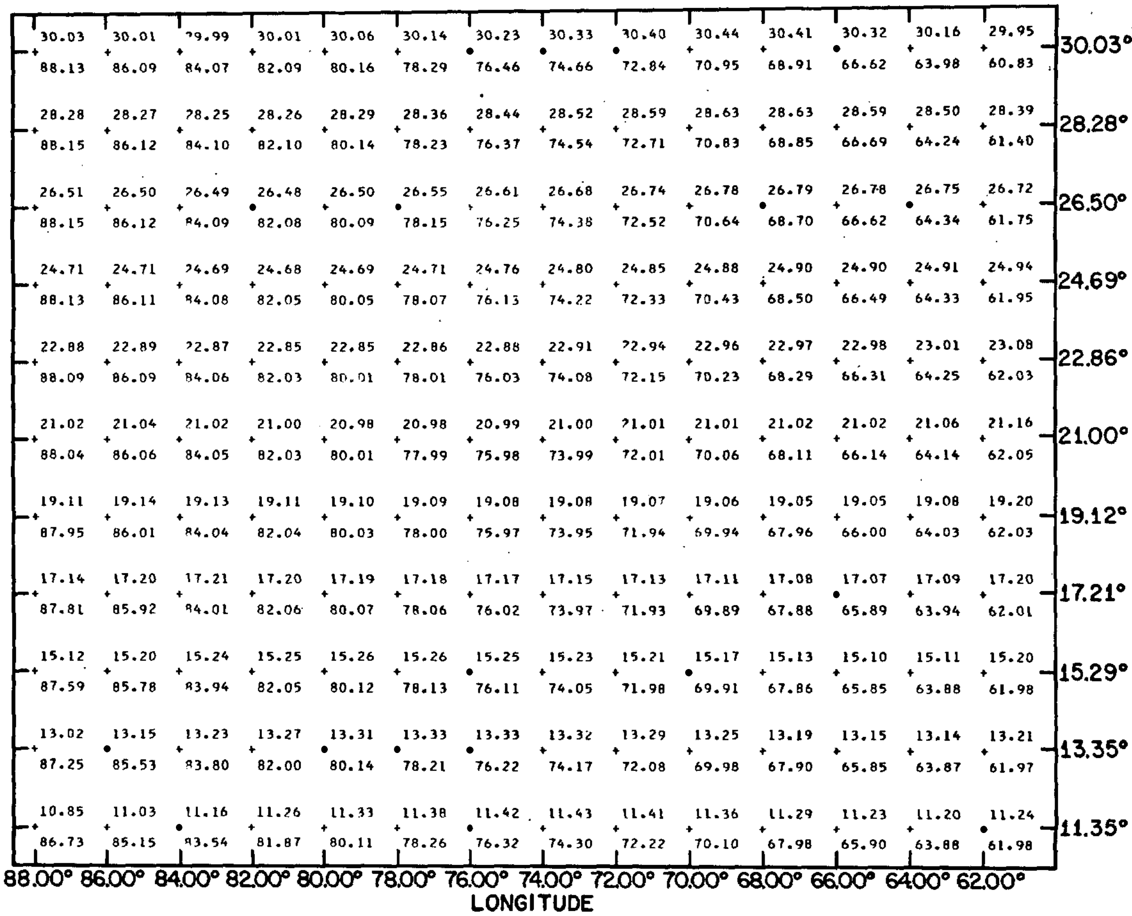
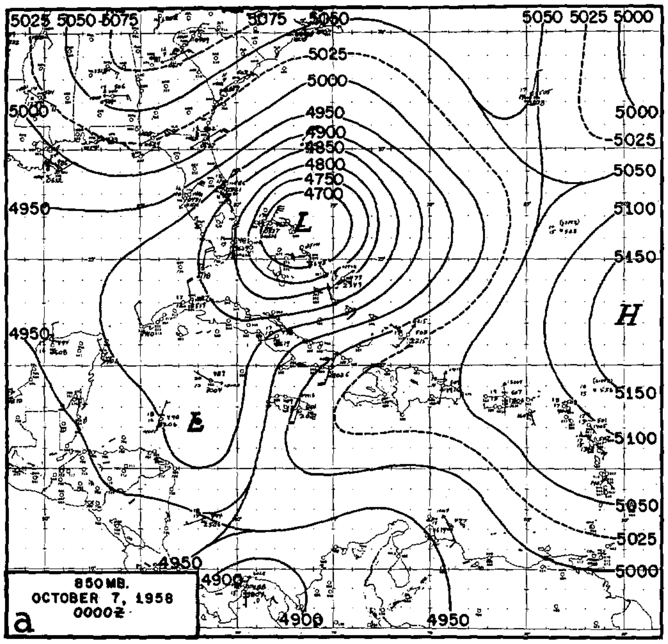
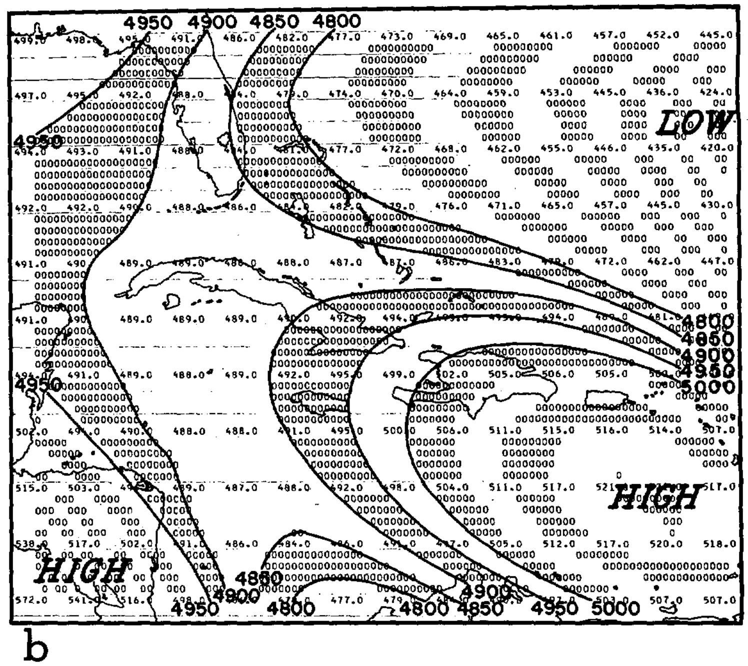


FIGURE 3.—Grid point values of latitude and longitude obtained by evaluation of interpolation polynomials derived through least-squares fitting of the latitude and longitude of 30 stations in the analysis area. Grid points are denoted by a plus sign (+). Computed latitude values are plotted to the upper right and computed longitude values to the lower right of the grid points. True latitude of the grid points is given along the right margin, and true longitude along the bottom margin.

TABLE 1.—*Departures of the fitted surfaces of latitude and longitude from the true latitude and longitude at 30 stations within the grid area.*

STATION NAME	STATION NUMBER	LATITUDE (deg.)	LATITUDE FITTED (deg.)	RESIDUAL (deg.)	LONGITUDE (deg.)	LONGITUDE FITTED (deg.)	RESIDUAL (deg.)
Charleston	208	32.90	32.90	-0.00	80.03	80.04	-0.01
Jackson	235	32.33	32.32	0.01	90.22	90.24	-0.02
Montgomery	226	32.30	32.34	-0.04	86.40	86.37	0.03
Bermuda	016	32.36	32.36	-0.00	64.66	64.66	0.00
Valparaiso	221	30.48	30.45	0.03	86.51	86.49	0.02
Jacksonville	206	30.41	30.36	0.05	81.65	81.69	-0.04
Burrwood	232	28.96	28.98	-0.02	89.37	89.36	0.01
Cape Kennedy	794	28.48	28.46	0.02	80.60	80.63	-0.03
Tampa	211	27.96	27.99	-0.03	82.53	82.49	0.04
Grand Bahama	063	26.62	26.72	-0.10	78.33	78.35	-0.02
Miami	202	25.81	25.78	0.03	80.28	80.27	0.01
Key West	201	24.58	24.59	-0.01	81.68	81.85	-0.17
San Salvador	089	24.05	24.13	-0.08	74.51	74.64	-0.13
Eleuthera	076	25.20	25.12	0.08	76.65	76.34	0.31
Camaguey	355	21.40	21.36	0.04	77.92	77.89	0.03
Turks Is.	118	21.58	21.50	0.08	71.13	71.26	-0.13
Merida	644	20.96	20.96	0.00	89.51	89.51	-0.00
Guantanamo	367	19.90	19.94	-0.04	75.15	75.16	-0.01
Grand Caymen	383	19.30	19.30	0.00	81.42	81.34	0.08
Santo Domingo	485	18.46	18.47	-0.01	69.88	69.82	0.06
San Juan	526	18.43	18.45	-0.02	66.11	66.06	0.05
St. Maarten	866	18.03	18.03	0.00	63.07	63.10	-0.03
Kingston	397	17.93	17.94	-0.01	76.78	76.81	-0.03
Swan Is.	501	17.40	17.40	-0.00	83.93	83.92	0.01
Antigua	861	17.11	17.12	-0.01	61.83	61.81	0.02
Guadeloupe	897	16.26	16.25	0.01	61.51	61.52	-0.01
San Andres	001	12.58	12.58	-0.00	81.66	81.70	-0.04
Curacao	988	12.18	12.18	0.00	68.98	68.99	-0.01
Trinidad	967	10.68	10.68	-0.00	61.61	61.61	-0.00
Balboa	805	08.96	08.96	0.00	79.55	79.53	0.02
		RMSE=	0.038 degrees		RMSE=	0.078 degrees	





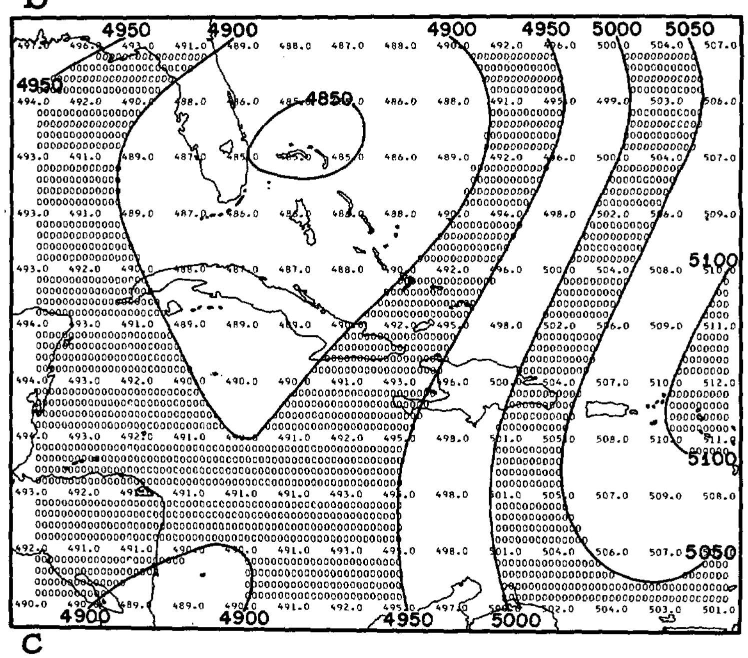


FIGURE 4.—(a) A conventional analysis of the 850-mb. pressure height surface at 0000 GMT, October 7, 1958. Isopleths are labeled in units of feet. (b) Analysis generated by least-squares fitting of a polynomial function to 31 station reports of 850-mb. height (0000 GMT October 7, 1958). Isopleths are labeled in units of feet. Height values at the grid points are given in tens of feet with the grid points denoted by the decimal point. (c) Analysis generated by least-squares fitting of a polynomial function to 31 station reports of 850-mb. height (0000 GMT, October 7, 1958) and height values specified at 19 control points. Labeling as in (b).

where m is the map scale factor, and $\sigma^*=\cos 22.5°/\cos\phi$ (ϕ=latitude) is the map projection transformation. Equation (5) then becomes

$$\Delta H^*=\frac{1}{g}\int_{X_i}^{X_s}\sigma f v dX-\frac{1}{g}\int_{Y_i}^{Y_s}\sigma f u dY \tag{7}$$

Using the wind data for the two stations in numerical evaluation of equation (7) yields the height increment approximation,

$$\Delta H=\frac{1}{2g}\{[(\sigma fv)_S+(\sigma fv)_i](X_S-X_i) \\ -[(\sigma fu)_S+(\sigma fu)_i](Y_S-Y_i)\} \tag{8}$$

The ith estimate to the height at station S is given by

$$H_{S_i}=H_i+\Delta H \tag{9}$$

The adjusted height H_{AS} at station S is the weighted sum of the estimates H_{S_i},

$$H_{AS}=\frac{H_S+\sum_{i=1}^{n}W_iH_{S_i}}{1+\sum_{i=1}^{n}W_i} \tag{10}$$

where n is the number of computed estimates, and H_S is

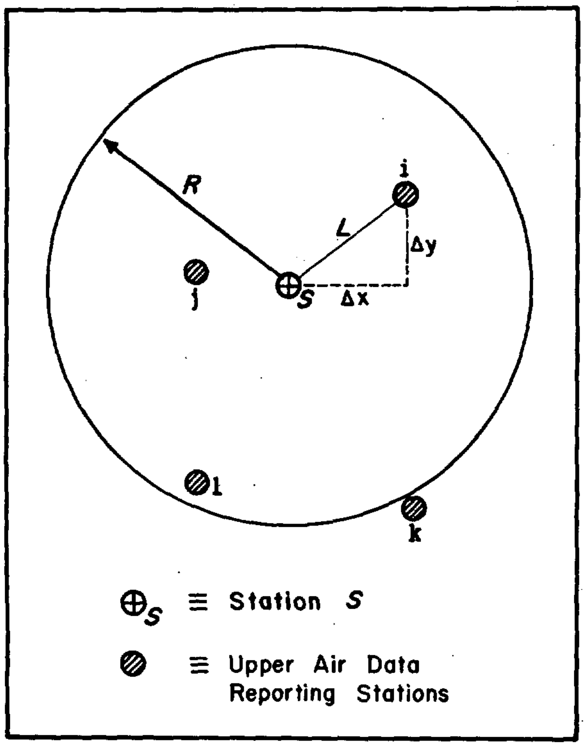


FIGURE 5.—Smoothing scan station circle of radius R about station S. Stations i, j, and l lie within the circle and their data would be used in computing H_S. The data from station k would not be used. L is the integration path used in the evaluation of $H^*_{S_i}$ (equation (4)).

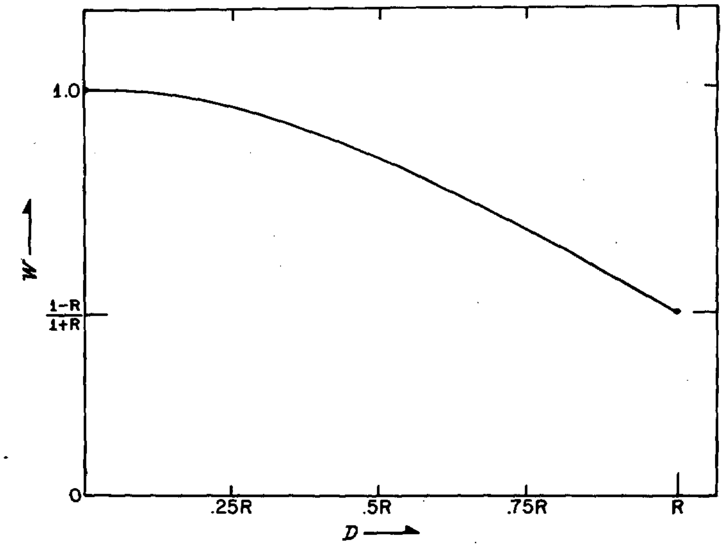


FIGURE 6.—Graph of the weighting function $W=(R-D^2)/(R+D^2)$, where R is the radius of the scan circle and D is the distance between the two stations.

the original height value for the station. H_S is included in the sum for two reasons: (1) for small radii R, the smoothing circle about a station may not contain other stations from which height estimates can be computed, and (2) in most cases the height value reported by a station is itself an excellent estimate.

The form of the weight W_i in equation (10) is

$$W_i=\frac{R-D_i^2}{R+D_i^2} \tag{11}$$

where D_i is the distance between station S and station i. Station i lies within the circle of radius R having station S at its center (fig. 5). W_i is defined only in the region bounded by this circle. In this region, the function is monotonic decreasing with a maximum value of one when $D=0$ and a minimum value of $(1-R)/(1+R)$ on the circle of radius R (fig. 6). This function allows nontrivial use of data from stations situated several grid increments away from station S; for the range of R normally used in smoothing (0°–10° of latitude), W_i has a lower bound of 1/3. The use of a weighting function which has a graph similar to that given by equation (11) but which goes to zero on the circle of radius R would require the use of larger scanning radii in data sparse regions. With large radii, the computed height estimates would not be meteorologically acceptable. Because of the lack of data, no discrimination is made on the basis of the relative positions or density of stations falling within a circle of influence.

A number of smoothing passes are made over the grid. The value of R is increased after $m(R)$ scans, where $m(R)$ was selected on the basis of the change of height estimate per scan. For each value of R, the current scan uses the adjusted heights computed during the previous scan. The initial scan, however, uses the original height data. The final smoothed height value for station S is then given by

$$H_{FS}=\sum_i C_i H_{AR_i}\Big/\sum_i C_i \tag{12}$$

With a small initial scanning radius R_1, the adjusted height H_{AR_1} is either the original height (when no other stations fall within the circle) or one computed from data from close-in stations. In the latter case, the height increment approximation ΔH is probably the most accurate estimate obtainable under the assumptions used in deriving equation (8). Table 2 shows the effect of the smoothing process on one set of height data with $R_1=1.5$, $R_2=2.5$, and $R_3=4.25$ grid increments. The weights C_i used in equation (12) are the mean values of the weighting functions W_i over the interval $[0, R_i]$,

$$C_i=\overline{W}_i=\frac{1}{R_i}\int_0^{R_i}\frac{R_i-D^2}{R_i+D^2}\,dD=2R_i^{-1/2}\tan^{-1}(R_i^{1/2})-1 \tag{13}$$

Hand analyses of station heights generated by the smoothing technique show that inconsistencies between the wind and height fields are eliminated satisfactorily.

Further experiments with other situations, however, pointed out several analysis deficiencies: (1) there was disagreement of the derived flow patterns with the reported winds, and (2) the height gradients did not agree with the gradients in the reported heights. Several attempts were made to improve the analysis by including the wind reports in residual equations. The quantities minimized included either a measure of the component of wind along the height gradient (equation (14)), or the deviations of the reported wind from the wind implied by the height field (equation (15));

$$Q_1=A_1 \sum_S (h-Z)^2+B_1 \sum_r (\mathbf{V}\cdot\nabla Z)^2 \qquad (14)$$

$$Q_2=A_2 \sum_S (h-Z)^2+B_2 \sum_r [(u-u_g)^2+(v-v_g)^2] \qquad (15)$$

In these equations h and $\mathbf{V}=u\mathbf{i}+v\mathbf{j}$ are, respectively, the observed geopotential heights and winds; S and r are the number of observations of each parameter; Z is given by equation (2), and

$$u_g=-\frac{g}{f}\frac{\partial}{\partial y}(Z) \qquad (16a)$$

$$v_g=\frac{g}{f}\frac{\partial}{\partial x}(Z) \qquad (16b)$$

A_1, A_2, B_1, B_2 are weighting factors (A_1, A_2 are dimensionless, B_1, B_2 have dimensions sec.^{2}) which determine the relative weight given the height and wind observations. The resulting height fields were overly smooth. As the magnitudes of the coefficients B_j were increased, the height field was subsequently flattened and the synoptic scale features were lost. A possible explanation of this is that the wind field exhibits more horizontal variation than that allowed by the polynomial form prescribed for the height field. Table 3 summarizes the results of tests made with equation (15); an increase in the weighting coefficient B_2 produced more smoothing of the height field which is signified by an increase in the root-mean-square error (RMSE). In all cases the smallest RMSE is associated with $B_2=0$. On the basis of these tests it was decided that the wind reports can not be used advantageously in the manner outlined above.

Since the wind reports provide $2r$ extra pieces of information, along with the S height reports, a method for using the wind data preliminary to the least-squares fitting process was devised. The method eliminates the need for "control" point data (which tend to damp the analysis), provides for a better agreement between the winds and the height field, and extends the analysis into data-void regions in a systematic manner which is similar to conventional techniques.

From the geostrophic relationship, the height report for a station is extrapolated out from the station by use of the relationships,

$$\Delta Z_y=-\frac{\Delta y}{g}fu \qquad (17a)$$

$$\Delta Z_x=\frac{\Delta x}{g}fv \qquad (17b)$$

where $f=2\omega \sin \phi$, u and v are the reported wind components, g is the gravitational acceleration, and Δy, Δx are the distances to be extrapolated latitudinally and longitudinally, respectively. Hence, a "generated" height H_g for a point Δy units north of a station having a reported height H_s is given by

$$H_g=H_s+\Delta Z_y \qquad (18)$$

By this means, the data distribution is altered from a systematic scatter along the grid diagonal to a quasi-uniform distribution over most of the grid. For each reporting station, a "star" of generated data points was subjectively selected. The number of points generated per station was taken as a function of the local density of actual observations. The "star" points are positioned at one-half grid intervals on the latitude and longitude lines which pass through the station. Only in extreme data voids are heights extrapolated farther than 5° from the station (fig. 7).

Figure 8 illustrates the augmented data distribution (the original grid (fig. 2) was expanded to the current one when a computer having a 32,768-word memory became available). The number of data available for the surface-fitting process is increased by an order of magnitude and the distribution is more favorable for fitting the interpolation polynomial.

The observed heights have more importance than the generated data; therefore, a set of weights was chosen empirically for the data such that the actual heights receive the largest weight. The generated data are assigned lesser weights which are a function of the extrapolation distances Δx, Δy. The least weight is given to the data generated at the largest distance from a station.

The new quantity minimized was

$$Q^*=\sum_s W_i(h_i-Z_i)^2 \qquad (19)$$

where W_i is the weight associated with the ith "observation", and s is now the total number of points used, i.e., the sum of the number of original height observations and the number of generated heights.

The analyses obtained using the "star" data are considerably better than those obtained by using only the original reports. This results from the fact that the winds are included in the analysis through the generation of the "star" data.

From the smoothed height values H_{FS} and the generated "star" data, the coefficients for the height interpolation polynomial are computed by minimizing Q^* given by equation (19). Analyses for several pressure surfaces were performed while varying the degree n of the polynomial (equation (2)) from 4 to 7. For each analysis the RMSE (computed at the reporting stations only) decreased when n was increased (table 4). Although higher-degree polynomials give smaller RMSE, they also produce surfaces which can have unrealistic variations

TABLE 2.—*Results of the height smoothing process applied to the 850-mb. height data for the 1200* GMT, *September 11, 1961 synoptic time period. Initial* H *is the height obtained by integration of the radiosonde data.* HA *is the adjusted height after eight smoothing scan passes.* K *is the number of stations falling within the scan circle of radius* R. *All heights are in meters.*

Station Number	Initial H	Scan Pass Number							HA	K
		1	2	3	4	5	6	7		
a. R equals 1½ grid increments										
001	1505.6	1505.6	1505.6	1505.6	1505.6	1505.6	1505.6	1505.6	1505.6	0
016	1563.5	1563.5	1563.5	1563.5	1563.5	1563.5	1563.5	1563.5	1563.5	0
063	1546.9	1546.3	1549.0	1549.8	1550.6	1551.1	1551.4	1551.7	1551.9	1
089	1537.1	1537.1	1537.1	1537.1	1537.1	1537.1	1537.1	1537.1	1537.1	0
118	1549.0	1546.3	1549.3	1550.4	1551.0	1551.4	1551.5	1551.6	1551.7	1
201	1558.1	1547.3	1547.8	1547.1	1546.8	1546.6	1546.4	1546.3	1546.2	2
202	1544.4	1551.0	1549.7	1550.3	1550.5	1550.7	1550.9	1551.0	1551.1	2
206	1561.5	1559.0	1560.2	1560.2	1560.2	1560.2	1560.1	1560.0	1559.9	3
208	1571.4	1571.4	1571.4	1571.4	1571.4	1571.4	1571.4	1571.4	1571.4	0
211	1561.8	1553.5	1551.9	1551.4	1551.0	1550.7	1550.6	1550.4	1550.3	2
214	1540.0	1548.7	1549.5	1550.6	1551.1	1551.3	1551.5	1551.6	1551.7	2
221	1543.5	1538.1	1539.3	1539.5	1539.8	1540.0	1540.2	1540.4	1540.5	2
226	1550.5	1552.1	1550.4	1550.1	1550.0	1550.1	1550.2	1550.4	1550.6	1
232	1502.7	1502.7	1502.7	1502.7	1502.7	1502.7	1502.7	1502.7	1502.7	0
304	1560.1	1560.1	1560.1	1560.1	1560.1	1560.1	1560.1	1560.1	1560.1	0
311	1570.1	1570.1	1570.1	1570.1	1570.1	1570.1	1570.1	1570.1	1570.1	0
325	1540.7	1547.7	1546.2	1545.6	1545.0	1544.5	1544.2	1543.9	1543.7	1
355	1529.8	1529.8	1529.8	1529.8	1529.8	1529.8	1529.8	1529.8	1529.8	0
367	1540.0	1532.8	1531.8	1531.7	1531.7	1531.7	1531.7	1531.7	1531.7	1
384	1540.9	1540.9	1540.9	1540.9	1540.9	1540.9	1540.9	1540.9	1540.9	0
397	1520.5	1527.7	1528.7	1528.8	1528.8	1528.8	1528.8	1528.8	1528.8	1
401	1540.0	1536.0	1535.7	1535.7	1535.7	1535.7	1535.7	1535.7	1535.7	2
403	1540.0	1537.1	1536.7	1536.6	1536.6	1536.6	1536.6	1536.6	1536.6	2
457	1540.0	1549.7	1548.5	1548.6	1548.6	1548.6	1548.6	1548.6	1548.6	2
467	1564.4	1552.9	1551.7	1550.4	1549.8	1549.5	1549.4	1549.3	1549.2	1
501	1521.5	1521.5	1521.5	1521.5	1521.5	1521.5	1521.5	1521.5	1521.5	0
526	1540.6	1540.7	1540.7	1540.0	1539.4	1538.9	1538.6	1538.4	1538.2	1
535	1540.0	1539.9	1538.3	1538.0	1537.6	1537.4	1537.3	1537.2	1537.1	3
644	1497.8	1497.8	1497.8	1497.8	1497.8	1497.8	1497.8	1497.8	1497.8	0
720	1540.0	1540.0	1540.0	1540.0	1540.0	1540.0	1540.0	1540.0	1540.0	0
794	1551.0	1557.9	1557.0	1556.6	1556.3	1556.0	1555.8	1555.7	1555.6	2
806	1503.5	1503.5	1503.5	1503.5	1503.5	1503.5	1503.5	1503.5	1503.5	0
861	1530.0	1533.9	1534.4	1534.7	1534.9	1535.1	1535.2	1535.3	1535.3	3
866	1540.5	1536.8	1536.9	1536.9	1537.0	1537.0	1537.1	1537.1	1537.1	4
894	1540.0	1536.5	1536.7	1536.7	1536.8	1536.8	1536.9	1536.9	1536.9	4
897	1526.5	1531.3	1532.1	1532.4	1532.7	1532.8	1532.9	1533.0	1533.0	3
967	1548.8	1548.8	1548.8	1548.8	1548.8	1548.8	1548.8	1548.8	1548.8	0
988	1530.2	1537.6	1538.4	1538.5	1538.5	1538.5	1538.5	1583.5	1583.5	2
b. R equals 2½ grid increments										
001	1505.6	1507.7	1508.1	1508.2	1508.2	1508.2	1508.2	1508.2	1508.2	1
016	1563.5	1563.5	1563.5	1563.5	1563.5	1563.5	1563.5	1563.5	1563.5	0
063	1546.9	1549.5	1549.3	1549.1	1548.8	1548.5	1548.3	1548.1	1548.0	5
089	1537.1	1541.6	1542.7	1543.4	1543.6	1543.7	1543.6	1543.6	1543.5	3
118	1549.0	1548.4	1546.6	1545.9	1545.4	1545.1	1544.9	1544.8	1544.7	4
201	1558.1	1545.8	1544.6	1543.7	1543.2	1542.8	1542.5	1542.4	1542.2	5
202	1544.4	1549.6	1548.8	1548.0	1547.5	1547.2	1546.9	1546.7	1546.6	5
206	1561.5	1559.3	1559.5	1559.7	1559.9	1560.0	1560.1	1560.2	1560.2	6
208	1571.4	1570.0	1569.8	1570.1	1570.3	1570.5	1570.6	1570.7	1570.8	3
211	1561.8	1551.5	1551.2	1551.0	1550.8	1550.7	1550.6	1550.5	1550.5	7
214	1540.0	1551.4	1551.8	1552.2	1552.5	1552.6	1552.8	1552.9	1553.0	6
221	1543.5	1541.5	1541.7	1542.0	1542.4	1542.6	1542.8	1543.0	1543.2	5
226	1550.5	1549.5	1551.1	1551.7	1552.2	1552.5	1552.8	1553.1	1553.3	4
232	1502.7	1504.0	1503.6	1503.9	1504.3	1504.7	1505.0	1505.3	1505.5	2
304	1560.1	1560.1	1560.1	1560.1	1560.1	1560.1	1560.1	1560.1	1560.1	0
311	1570.1	1568.7	1569.6	1570.2	1570.6	1570.9	1571.1	1571.3	1571.5	4
325	1540.7	1544.6	1542.2	1541.8	1541.4	1541.1	1541.0	1540.8	1540.6	3
355	1529.8	1529.8	1529.8	1529.8	1529.8	1529.8	1529.8	1529.8	1529.8	0
367	1540.0	1536.2	1539.6	1540.4	1541.0	1541.4	1541.6	1541.7	1541.7	4
384	1540.9	1534.7	1538.6	1539.4	1540.1	1540.3	1540.5	1540.5	1540.4	3
397	1520.5	1532.1	1533.9	1536.9	1538.5	1539.5	1540.2	1540.5	1540.7	2
401	1540.0	1535.8	1535.6	1535.6	1535.6	1535.6	1535.6	1535.6	1535.6	2
403	1540.0	1536.9	1536.6	1536.6	1536.6	1536.6	1536.6	1536.6	1536.6	2
457	1540.0	1547.1	1544.6	1543.5	1542.8	1542.3	1542.1	1541.9	1541.8	4
467	1564.4	1547.2	1545.4	1543.7	1542.8	1542.3	1542.0	1541.8	1541.7	4
501	1521.5	1532.2	1531.1	1530.8	1530.2	1529.7	1529.2	1528.8	1528.4	2
526	1540.6	1543.2	1541.9	1541.4	1541.1	1541.0	1540.9	1540.9	1540.9	6
535	1540.0	1541.5	1540.3	1540.2	1540.2	1540.2	1540.2	1540.3	1540.3	6
644	1497.8	1497.8	1497.8	1497.8	1497.8	1497.8	1497.8	1497.8	1497.8	0
720	1540.0	1526.6	1522.5	1519.5	1517.6	1516.2	1515.2	1514.3	1513.7	1
794	1551.0	1557.2	1557.2	1557.0	1556.8	1556.7	1556.6	1556.5	1556.5	7
806	1503.5	1501.3	1500.9	1500.9	1500.9	1500.8	1500.8	1500.8	1500.8	1
861	1530.0	1534.5	1535.7	1536.2	1536.6	1536.8	1536.9	1537.0	1537.1	5
866	1540.5	1537.2	1538.3	1538.7	1539.0	1539.2	1539.3	1539.4	1539.5	5
894	1540.0	1536.9	1538.0	1538.5	1538.8	1539.0	1539.1	1539.2	1539.3	5
897	1526.5	1532.0	1533.1	1533.9	1534.4	1534.7	1534.9	1535.0	1535.1	4
967	1548.8	1548.8	1548.8	1548.8	1548.8	1548.8	1548.8	1548.8	1548.8	0
988	1530.2	1537.9	1538.4	1538.4	1538.4	1538.4	1538.4	1538.4	1538.4	2

TABLE 2.—Concluded.

Station Number	Initial H	Scan Pass Number							HA	K
		1	2	3	4	5	6	7		
c. R equals 4¼ grid increments										
001	1505.6	1515.9	1516.0	1516.2	1516.3	1516.4	1516.5	1516.5	1516.5	5
016	1563.5	1563.5	1563.5	1563.5	1563.5	1563.5	1563.5	1563.5	1563.5	0
063	1546.9	1548.6	1548.2	1547.9	1547.7	1547.6	1547.6	1547.5	1547.5	10
089	1537.1	1544.8	1544.8	1544.6	1544.4	1544.3	1544.2	1544.2	1544.1	10
118	1549.0	1546.3	1545.5	1545.5	1545.5	1545.5	1545.5	1545.5	1545.6	7
201	1558.1	1543.5	1542.5	1542.0	1541.8	1541.6	1541.5	1541.5	1541.5	11
202	1544.4	1547.5	1546.6	1546.2	1546.1	1546.0	1545.9	1545.9	1545.9	12
206	1561.5	1560.3	1560.0	1560.0	1560.1	1560.1	1560.1	1560.2	1560.2	12
208	1571.4	1568.4	1569.8	1570.2	1570.6	1570.8	1570.9	1571.0	1571.1	10
211	1561.8	1550.4	1549.7	1549.6	1549.6	1549.6	1549.6	1549.6	1549.7	12
214	1540.0	1553.2	1553.1	1553.2	1553.2	1553.3	1553.3	1553.4	1553.4	11
221	1543.5	1543.1	1543.1	1543.3	1543.4	1543.5	1543.5	1543.6	1543.6	10
226	1550.5	1552.8	1553.6	1554.0	1554.2	1554.3	1554.4	1554.5	1554.5	8
232	1502.7	1502.3	1503.1	1503.3	1503.4	1503.5	1503.6	1503.6	1503.7	5
304	1560.1	1569.3	1572.5	1574.7	1576.0	1576.8	1577.3	1577.6	1577.8	2
311	1570.1	1569.3	1570.5	1571.1	1571.4	1571.6	1571.8	1571.9	1572.0	8
325	1540.7	1541.2	1540.8	1540.5	1540.3	1540.1	1540.0	1539.9	1539.8	12
355	1529.8	1533.3	1537.7	1539.8	1541.1	1541.9	1542.5	1542.9	1543.1	4
367	1540.0	1538.3	1538.5	1538.4	1538.3	1538.2	1538.1	1538.0	1538.0	9
384	1540.9	1535.3	1534.5	1534.0	1533.7	1533.5	1533.4	1533.3	1533.2	8
397	1520.5	1535.0	1536.4	1536.4	1536.3	1536.2	1536.1	1536.1	1536.0	9
401	1540.0	1537.0	1534.3	1531.9	1530.0	1528.5	1527.4	1526.6	1525.9	3
403	1540.0	1537.6	1534.6	1532.2	1530.4	1528.9	1527.8	1527.0	1526.3	3
457	1540.0	1543.0	1542.5	1542.5	1542.5	1542.5	1542.5	1542.5	1542.6	10
467	1564.4	1541.5	1541.4	1541.4	1541.5	1541.5	1541.6	1541.6	1541.7	11
501	1521.5	1525.1	1524.6	1524.2	1523.9	1523.7	1523.5	1523.4	1523.3	7
526	1540.6	1542.7	1543.0	1543.1	1543.4	1543.6	1543.8	1543.9	1544.0	9
535	1540.0	1541.9	1542.4	1542.6	1542.8	1543.1	1543.3	1543.4	1543.5	9
644	1497.8	1510.3	1512.0	1512.0	1511.7	1511.4	1511.1	1510.9	1510.8	3
720	1540.0	1517.8	1515.1	1514.3	1514.0	1513.8	1513.6	1513.5	1513.4	4
794	1551.0	1555.0	1554.8	1554.7	1554.7	1554.6	1554.7	1554.7	1554.7	12
806	1503.5	1501.1	1504.4	1506.3	1507.4	1508.1	1508.5	1508.8	1508.9	1
861	1530.0	1538.7	1539.4	1540.2	1540.8	1541.3	1541.6	1541.8	1541.9	8
866	1540.5	1541.3	1541.8	1542.5	1543.0	1543.4	1543.7	1543.9	1544.1	9
894	1540.0	1541.0	1541.6	1542.3	1542.9	1543.2	1543.5	1543.7	1543.9	9
897	1526.5	1534.9	1537.0	1537.9	1538.5	1539.0	1539.3	1539.5	1539.6	7
967	1548.8	1534.1	1533.4	1532.7	1532.1	1531.6	1531.2	1530.9	1530.7	7
988	1530.2	1536.0	1533.2	1531.7	1530.5	1529.7	1529.0	1528.5	1528.2	7

TABLE 3.—*Relationship between the coefficients A_2 and B_2 of the residual equation (15), and the resultant RMSE of the fitted surface. Data are from 1200 GMT, August 13, 1963, synoptic time period.*

p-surface	A_2	B_2/A_2	RMSE (meters)
1000 mb.	1.0	1.00	7.353
1000 mb.	1.0	0.25	4.539
1000 mb.	1.0	0.0	4.133
850 mb.	1.0	1.00	8.178
850 mb.	1.0	0.25	5.194
850 mb.	1.0	0.0	3.693
200 mb.	9.0	0.028	11.445
200 mb.	9.0	0.011	10.041
200 mb.	9.0	0.0	9.034

TABLE 4.—*Relationship between the degree n of the bivariate interpolation polynomial and the RMSE of the resultant fitted surface. Data are for 29 height and wind reporting stations from the 1200 GMT, October 1, 1964, synoptic time period.*

n	Number of terms in the interpolation polynomial	RMSE (meters)	
		700 mb.	200 mb.
3	10	3.760	16.369
4	15	2.788	10.525
	18	2.227	9.635
5	21	1.800	6.969
	25	1.638	6.011
6	28	1.374	4.889
	32	1.179	4.367
7	36	0.996	2.402

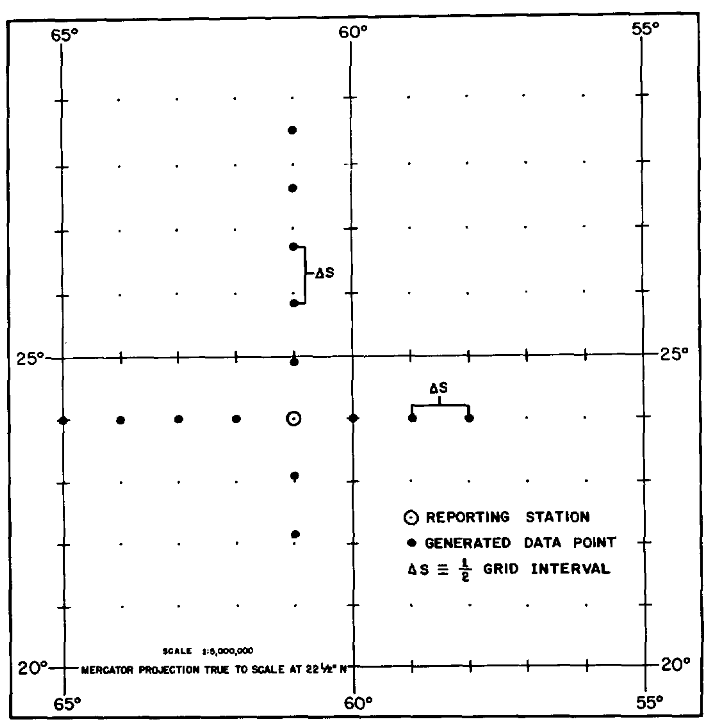


FIGURE 7.—A typical "star" data point plot-out consisting of the reporting station and generated data points.

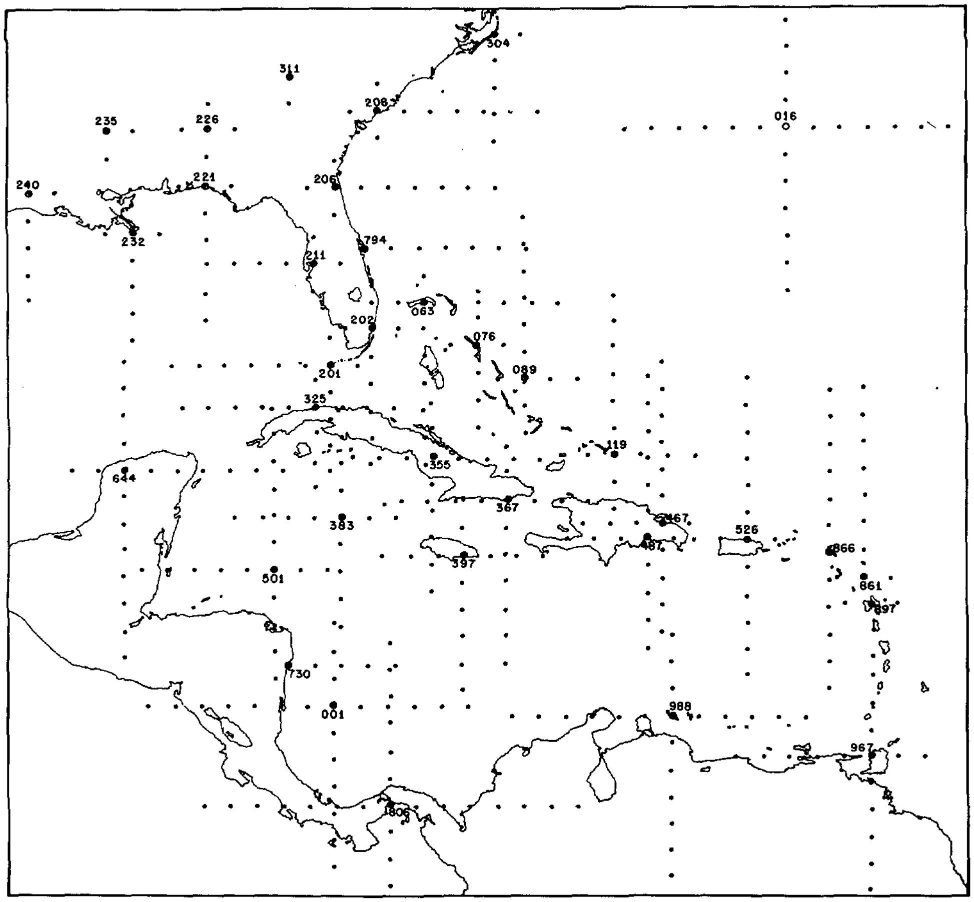


FIGURE 8.—A typical distribution of the generated data points.

between stations. For this reason, small RMSE does not imply that the generated polynomial surface is the most satisfying one. The final choice of $n(=6)$ was based on both the RMSE and synoptic representativeness of analyses for a series of cases which included several pressure surfaces and a number of different synoptic situations.

The polynomial surfaces produced by the above described method represent the synoptic scale meteorological patterns reasonably well. However, further improvement is obtained by using a Cressman type iteration with the least-squares generated surface used as the first guess field. In a series of scans over the grid, the height value at a grid point is adjusted by recomputing a value which is partially dependent on the height and wind data of stations which lie within a specified circle of radius R centered on the grid point. The adjusted grid point height at scan i, using circles of radius R_i, is given by

$$H_{Ag}^{(i)}=\frac{W_g^{(i)}H_{Ag}^{(i-1)}+\sum_{j=1}^{n}W_jH_{Ej}}{W_g^{(i)}+\sum_{j=1}^{n}W_j} \tag{20}$$

Here, $H_{Ag}^{(i-1)}$ is the adjusted grid-point value from the previous scan, $W_g^{(i)}$ is the weight given the previous approximation, W_j is the weighting function given by equation (11), H_{Ej} is a height estimate for the grid point based on the height and wind values of station j, and n is the total number of stations falling within the circle of radius R_i. H_{Ej} is given by

$$H_{Ej}=H_j+\frac{(\sigma f)_j}{g}\{u_j(Y_j-Y_g)-v_j(X_j-X_g)\} \tag{21}$$

This represents an extrapolation of the station height H_j to the grid point and uses the observed winds as the geostrophic approximation to the height gradient. The symbols used in (21) are the same as those defined in the derivation of equation (8). The value of R is decreased for each succeeding scan so that the ratio of the areas bounded by the scan circles (R_{i+1}^2/R_i^2) is approximately 1/3.

For large values of the scan radius R_i, the extrapolation formula (21) may give undesirably large adjustments if the distance between the grid point and scanned station approaches R_i. In order to suppress this effect, a nine-point smoothing function is applied to the grid values before each adjustment scan (with the exception of the first). The smoothing function has the form

$$\overline{Z}_0=(1-\nu)^2Z_0+\frac{1}{2}\nu(1-\nu)\sum_1^4 Z_{\text{even}}+\frac{1}{4}\nu^2\sum_1^4 Z_{\text{odd}} \tag{22}$$

where $\overline{Z}_0(Z_0)$ is the smoothed (unsmoothed) value at the point 0, Z_{even} is a value at a longitudinally or latitudinally adjacent grid point, and Z_{odd} is a value at a diagonally adjacent grid point.

The properties of this smoothing function have been discussed by Shuman [9]. The value of the coefficient ν was chosen so that the weight of Z_0 in equation (22) is at least 80 percent. With this value, disturbances which have wavelengths of two grid increments have their amplitudes damped by, at most, 40 percent. Damping the amplitudes by more than 40 percent also tends to suppress desired synoptic features of a somewhat larger scale.

3. THE FINAL WORKING SYSTEM

For a synoptic time, the following procedure produces objectively analyzed pressure height on any of 20 isobaric surfaces at 50-mb. intervals starting at 1000 mb.

(1) All upper-air data for stations within and contiguous to the grid area are put on punched cards for input to the preprocessing (ADP) program. At each station, ADP checks for vertical consistency of the radiosonde data, merges the upper wind reports (if any) with the winds given by the radiosonde message, interpolates and computes the desired meteorological parameter values for each of the 20 isobaric surfaces, and assigns the transformed space coordinates to the station. A magnetic tape record is made which contains this information stratified according to level (ADP tape).

(2) Data for one isobaric surface are read from the ADP tape. Jordan's [7] mean height is assigned to stations which have a wind report only. By means of the wind data, the reported height values are smoothed in several iterative passes over the grid with scanning radii of 1.5, 2.5, and 4.25 grid increments. The final smoothed height is computed from equation (12).

(3) The "star" data are generated from the station data from equations (17a), (17b), and (18).

(4) The augmented height data are used to obtain a least-squares fit polynomial surface of degree $n=6$ by minimizing Q^* in equation (19). A weight of 16 is assigned to the station height, a weight of 4 is assigned to the generated height values which are one-half a grid interval away from the station (fig. 7), and a weight of 1 is assigned to the remaining generated heights.

(5) Grid-point heights are computed from the derived interpolation polynomial. These values are adjusted on the basis of the station data in a series of scans over the grid by the use of equations (20) and (21), and scanning radii of 4.25, 2.5, and 1.5 grid increments. $W_g^{(i)}$ (equation (20)) is assigned the corresponding values of 2, 1.5, and 1. Equation (22) is used to smooth the adjusted grid-point values after scans one and two. The smoothing coefficient ν is given the value 0.10. The surface resulting from the third modification scan is taken to be the objective analysis of the isobaric surface.

4. RESULTS

Objective analyses of pressure height data for several synoptic map times are presented in figures 9 through 18 along with the corresponding conventional subjective analyses. Tables 5 through 14 contain the input and comparative data for these analyses. The cases chosen for presentation were selected because of interesting synoptic-scale features present during the time period. Analyses performed for other times, when the atmosphere was less active, gave even better results.

All objective techniques are limited by the quantity of data available. At the time of this report, computer limitations prevented the use of all of the available aircraft and ship reports. A limited number of these data were used for several of the objective analyses presented here (see tables 5, 8, and 10); the inclusion of all available data in the objective analysis would strengthen the representation of the synoptic scale features.

The conventional analyses shown here are not consensuses of opinion as to the "true" state of the atmosphere. They represent the efforts of a single skilled analyst. Close examination of the plotted data will show many areas of analysis which are open to re-interpretation. Also, aircraft wind data and ship reports, not available to the objective technique, have been used to supplement the subjective analyses.

Tables 9–14 show two values of root-mean-square error (RMSE). The first was based on the differences between the smoothed input data and the station values given by the polynomial. The second was computed from the objective analysis and was based on the differences between the smoothed input data and values interpolated at the stations from the grid-point data. A nine-point finite difference form of the truncated Taylor's expansion of a function of two variables was used for the interpolation.

HEIGHT ANALYSES FOR 1200 GMT, SEPTEMBER 30, 1964

1000 mb. (*fig. 9, table 5*). Although the subjectively analyzed (SA) map was drawn with the aid of a large number of surface reports, there is good agreement between the objective analysis (OA) and conventional analysis. The OA positioning of the unnamed tropical storm (Hilda as of 1600 GMT) is satisfactory; the height gradient about the storm is acceptable. The synoptic-scale troughs and ridges (fig. 9a) are well positioned and their amplitudes agree fairly well with those subjectively analyzed.

700 mb. (*fig. 10, table 6*). There is good overall agreement between the analyses. The OA trough positioning north of Yucatan is correct, but the height gradient is weak in the area of the storm. The closed Low (SA) north of Yucatan was positioned on the basis of space-time continuity. The 3150-m. line in the Central America-southern Caribbean region on both analyses is an indication of the sparse data in this region.

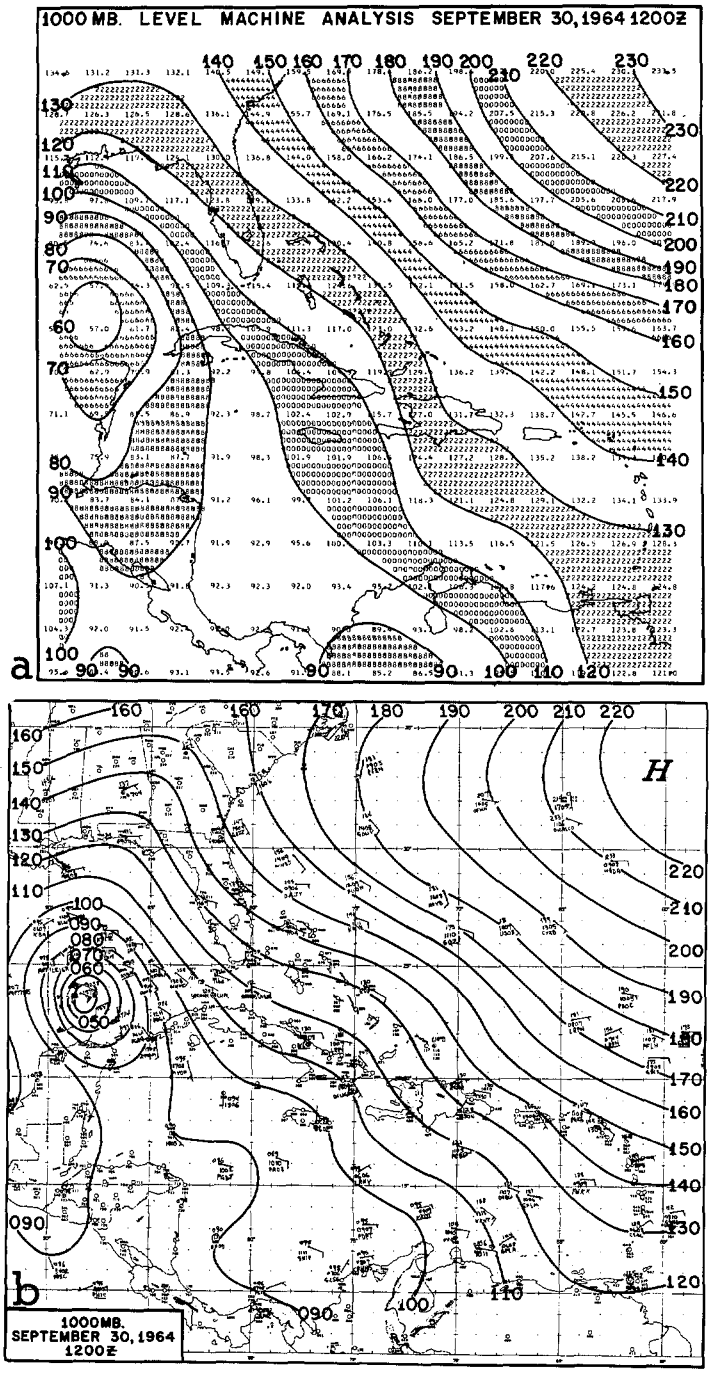


FIGURE 9.—1000-mb. pressure-height surface, 1200 GMT, September 30, 1964. (a) Objective analysis. Isopleths are labeled in units of meters. Grid-point values are given in meters with the decimal point denoting the grid point. (b) Conventional analysis. Isopleths are labeled in units of meters.

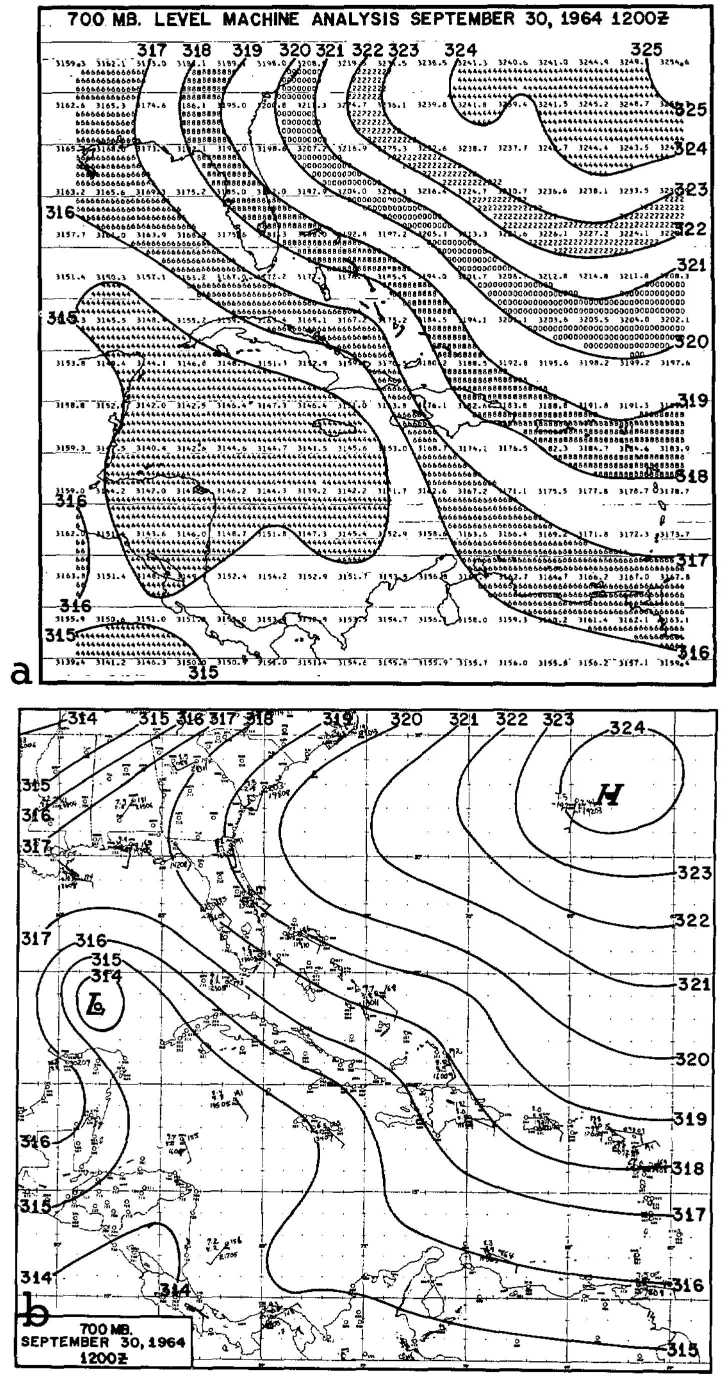


FIGURE 10.—700-mb. pressure-height surface, 1200 GMT, September 30, 1964. (a) Objective analysis. (b) Conventional analysis. All isopleths are labeled in units of tens of meters. Grid-point labeling as in figure 9.

TABLE 5.—*1000-mb. pressure-height data for 1200* GMT, *September 30, 1964. OH=height computed from radiosonde data, SH=smoothed height given by equation (12), FH=value of the interpolation function at the station, RES=difference of SH and FH, AH=height obtained through the iterative-correction process, ARES=difference of SH and AH, DD=wind direction in degrees, and FF=wind speed in knots. An asterisk indicates no adjusted height was obtained because the station was outside the grid. All heights are in meters. A and S prefixing the station number designate, respectively, aircraft and ship reports.*

STATION	OH	SH	FH	RES	AH	ARES	DD	FF
001	89.8	92.1	94.9	-2.8	92.2	-0.1	0	0
016	212.0	220.5	221.6	-1.1	220.9	-0.4	170	10
063	138.0	125.8	127.8	-2.0	125.7	0.1	110	7
089	127.1	126.3	131.6	-5.4	126.7	-0.5	120	16
118	149.1	137.5	133.6	3.9	133.7	3.8	150	19
201	118.3	109.8	102.8	6.9	110.5	-0.7	110	12
202	127.2	119.9	115.2	4.7	119.2	0.7	110	11
206	153.2	133.5	135.1	-1.6	132.6	1.0	140	12
208	161.4	149.4	147.6	1.7	*	*	160	12
211	130.6	120.3	117.3	3.0	120.9	-0.5	110	13
214	123.0	126.2	127.0	-0.8	124.5	1.6	106	10
221	115.9	122.3	120.6	1.7	120.5	1.8	90	8
226	138.8	128.1	134.0	-5.9	128.3	-0.2	70	8
232	117.6	99.3	99.6	-0.3	103.0	-3.7	80	12
235	145.5	132.5	129.4	3.2	131.9	0.7	20	6
240	133.0	129.6	125.8	3.8	*	*	30	9
248	155.7	138.4	145.2	-6.8	*	*	30	8
304	160.3	165.3	165.6	-0.2	*	*	220	17
308	156.6	151.6	152.2	-0.7	*	*	230	18
340	163.1	145.5	142.3	3.2	*	*	50	6
384	91.1	94.5	92.8	1.7	94.1	*	180	12
397	97.3	100.4	106.2	-5.8	101.4	-1.0	0	4
486	128.0	129.4	127.5	1.9	130.3	-0.9	30	8
501	89.4	89.0	83.6	5.4	87.8	1.2	140	6
526	146.0	138.7	138.0	0.7	137.2	1.5	150	12
644	89.8	65.4	64.6	0.9	69.4	-3.9	270	8
794	136.8	130.4	130.1	0.3	129.7	0.7	130	11
806	92.2	92.2	91.4	0.8	92.1	0.1	330	4
861	152.9	138.7	138.6	0.1	139.4	-0.8	96	13
866	144.3	140.3	140.9	-0.6	141.2	-0.9	130	18
894	123.0	139.9	140.7	-0.8	141.1	-1.3	125	10
897	139.5	137.0	136.3	0.7	137.1	-0.1	80	10
967	125.0	125.2	125.5	-0.3	124.3	0.8	0	0
988	106.8	109.7	110.3	-0.5	110.6	-0.9	100	21
A25.3N 85.3W	104.0	78.4	86.6	-8.2	83.6	-5.2	121	22
A24.0N 86.4W	69.0	67.9	74.6	-6.7	66.4	1.6	154	32
A23.4N 87.4W	35.0	62.1	68.0	-5.8	57.4	4.7	174	40
A23.5N 88.9W	0.0	67.4	64.6	2.8	56.4	11.0	352	42
S25.4N 89.6W	75.0	73.1	71.9	1.2	66.0	7.0	50	25
S23.0N 88.5W	0.0	63.4	63.9	-0.5	56.7	6.7	270	19
S31.5N 64.7W	232.0	216.9	218.4	-1.5	218.1	-1.2	110	12
S26.6N 70.0W	174.0	167.6	165.0	2.6	165.9	1.7	110	20
S29.7N 74.2W	169.0	162.4	162.5	-0.1	163.2	-0.8	110	16
S33.7N 74.5W	180.0	172.4	172.3	0.1	*	*	190	10
S26.6N 90.3W	90.0	82.2	80.0	2.2	82.6	-0.4	60	14
				45 STATIONS		38 STATIONS		
				RMSE=3.350 m.		RMSE=2.970 m.		

TABLE 6.—*700-mb. pressure-height data for 1200* GMT, *September 30, 1964. See table 5 for explanation of symbols.*

STATION	OH	SH	FH	RES	AH	ARES	DD	FF
001	3155.4	3152.2	3148.0	4.2	3150.5	1.6	220	12
016	3243.8	3243.8	3244.9	-1.1	3243.9	-0.1	190	6
063	3185.5	3187.0	3185.6	1.4	3187.7	-0.6	120	17
089	3167.7	3179.1	3183.2	-4.1	3179.9	-0.8	130	23
118	3191.4	3186.8	3183.2	3.6	3185.1	1.7	160	17
201	3172.6	3169.0	3165.6	3.4	3167.2	1.8	120	10
202	3173.4	3177.2	3175.4	1.9	3176.8	0.4	130	18
206	3190.9	3190.9	3191.9	-1.0	3193.5	-2.6	170	10
208	3202.3	3197.7	3197.8	-0.1	*	*	200	14
211	3184.9	3180.8	3181.2	-0.4	3181.3	-0.5	140	15
214	3178.0	3179.7	3182.5	-2.8	3181.8	-2.1	142	18
221	3162.8	3171.5	3174.4	-3.0	3172.3	-0.8	190	10
222	3161.0	3156.7	3156.7	0.0	*	*	70	10
226	3181.0	3170.1	3172.7	-2.6	3172.2	-2.1	210	12
232	3174.1	3166.4	3163.9	2.5	3165.3	1.1	100	8
235	3160.5	3161.7	3157.7	4.0	3161.1	0.6	250	3
240	3158.7	3157.0	3157.7	-0.7	*	*	220	6
248	3142.8	3155.6	3156.1	-0.5	*	*	100	2
304	3190.7	3206.5	3206.0	0.5	*	*	230	25
308	3184.6	3182.7	3183.8	-1.1	*	*	240	28
311	3194.2	3181.9	3179.7	2.2	•	*	250	19
317	3180.7	3177.0	3177.8	-0.9	*	*	230	25
327	3141.9	3151.5	3150.8	0.7	*	*	250	9
340	3143.4	3148.0	3148.8	-0.8	*	*	260	14
384	3141.0	3144.6	3144.5	0.1	3147.1	-2.5	150	10
397	3122.5	3142.4	3147.8	-5.4	3144.8	-2.4	130	15
486	3182.3	3179.1	3175.8	3.2	3180.1	-1.1	110	14
501	3155.0	3144.2	3144.0	0.2	3142.7	1.5	160	12
526	3191.9	3186.5	3187.7	-1.3	3186.3	0.2	140	20
644	3160.9	3153.9	3153.3	0.7	3152.8	1.2	300	14
794	3194.2	3190.8	3190.3	0.4	3192.3	-1.5	130	15
806	3147.8	3150.7	3153.6	-2.8	3152.6	-1.9	70	10
861	3193.7	3183.5	3183.3	0.2	3184.2	-0.7	70	9
866	3188.1	3186.4	3187.5	-1.1	3187.9	-1.5	120	18
894	3178.0	3186.1	3186.9	-0.8	3187.2	-1.1	97	15
897	3168.3	3181.5	3180.7	0.8	3181.6	-0.1	80	10
967	3164.8	3165.3	3164.8	0.5	3165.3	-0.0	100	16
988	3163.8	3163.5	3163.3	0.2	3163.1	0.4	110	10
				38 STATIONS		28 STATIONS		
				RMSE=2.146 m.		RMSE=1.396 m.		

400 mb. (*fig. 11, table 7*). The positioning of the major synoptic systems is basically the same on both analyses. The OA placed a low center to the southeast of Kingston (397) with a trough extending over Cuba to the northwest and a second trough extending to the southwest. On the subjective analysis, both the Low positioned over Cuba and the high center east of Florida are open to conjecture. The low center northeast of Merida (644) is not shown on the OA since there were no data to support it; the SA positioning of this Low is based on continuity. The grid-point values in the extreme southwest reflect the complete absence of data in this area.

250 mb. (*fig. 12, table 8*). Aircraft data were used to support both analyses in the Gulf of Mexico area. The SA Low south of Bermuda (016) and the High to its east are based on continuity and data off the map. The OA positioning of the ridges and troughs agrees well with the data used in the analysis; the RMSE is less than 5 m. (table 8). In general, the contour patterns at this pressure level are very complex and are difficult to draw, either objectively or subjectively.

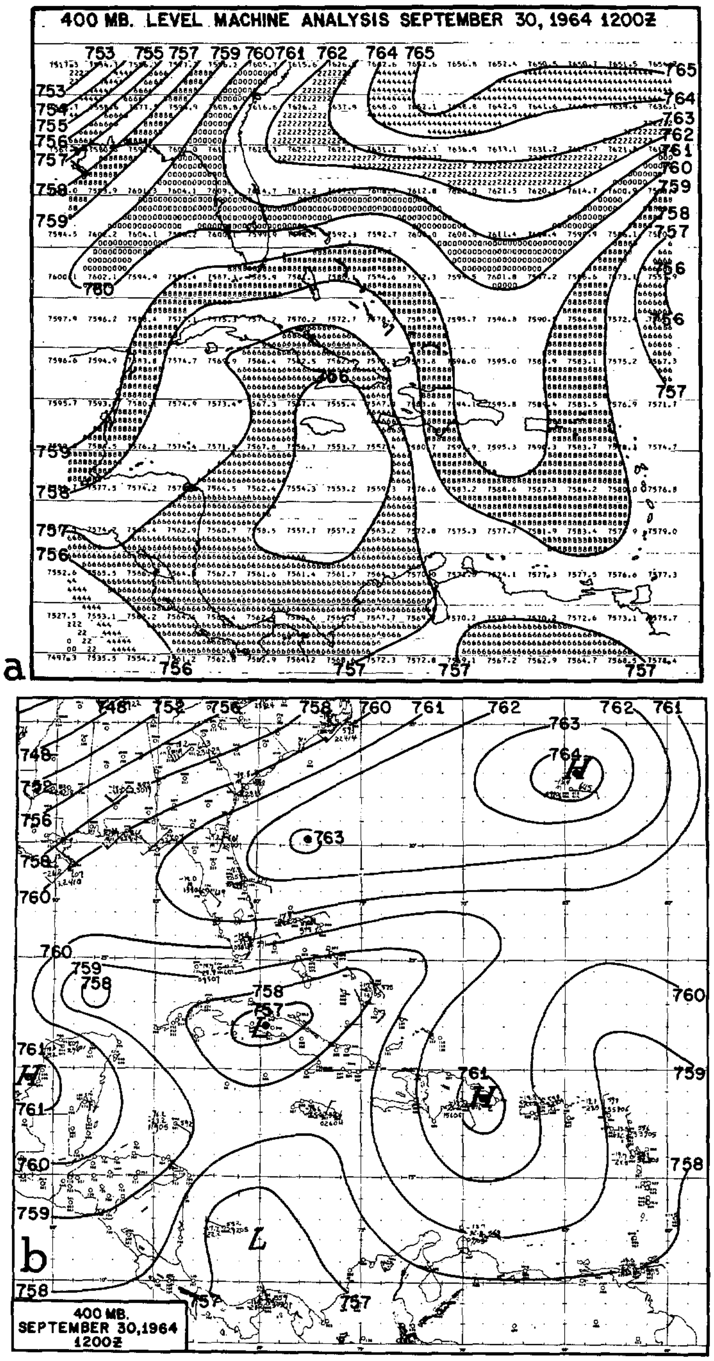


FIGURE 11.—400-mb. pressure-height surface, 1200 GMT, September 30, 1964. (a) Objective analysis. (b) Conventional analysis. Labeling as in figure 10.

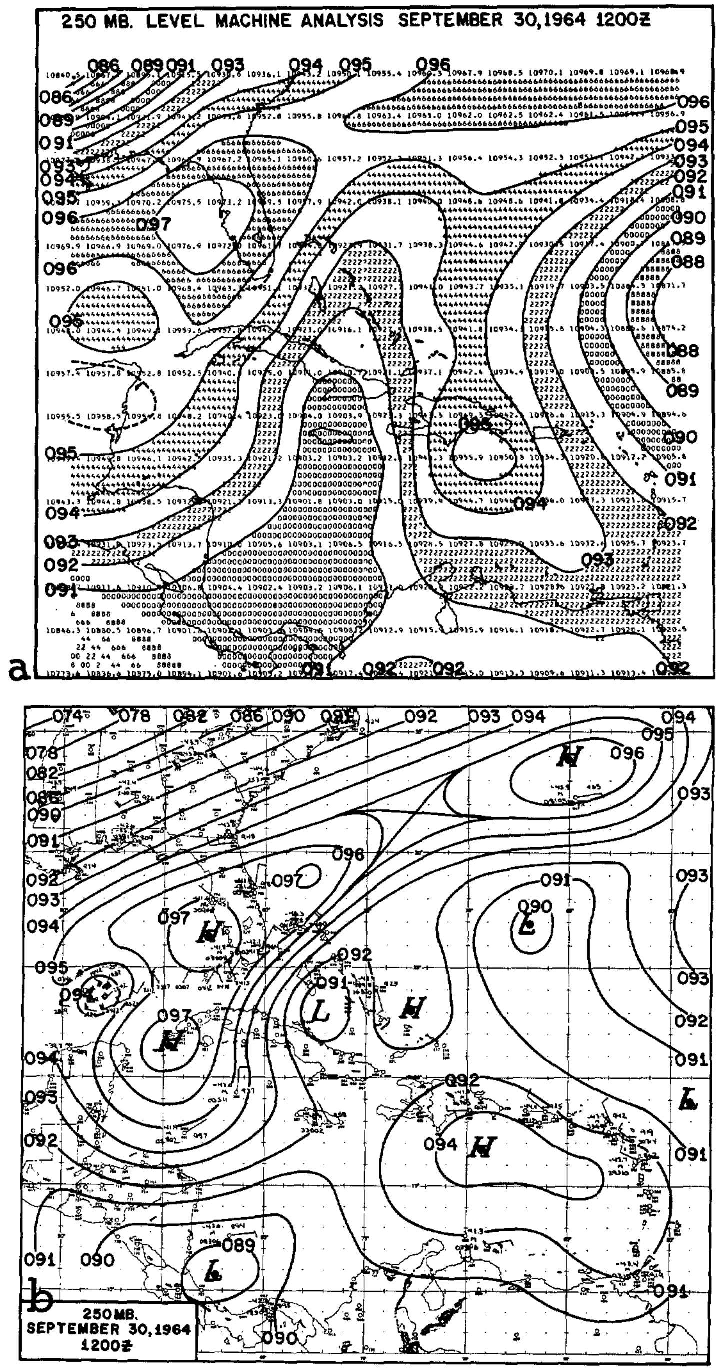


FIGURE 12.—250-mb. pressure-height surface, 1200 GMT, September 30, 1964. (a) Objective analysis. (b) Conventional analysis. All isopleths are labeled in units of tens of meters with the leading significant digit suppressed. Grid-point labeling as in figure 9.

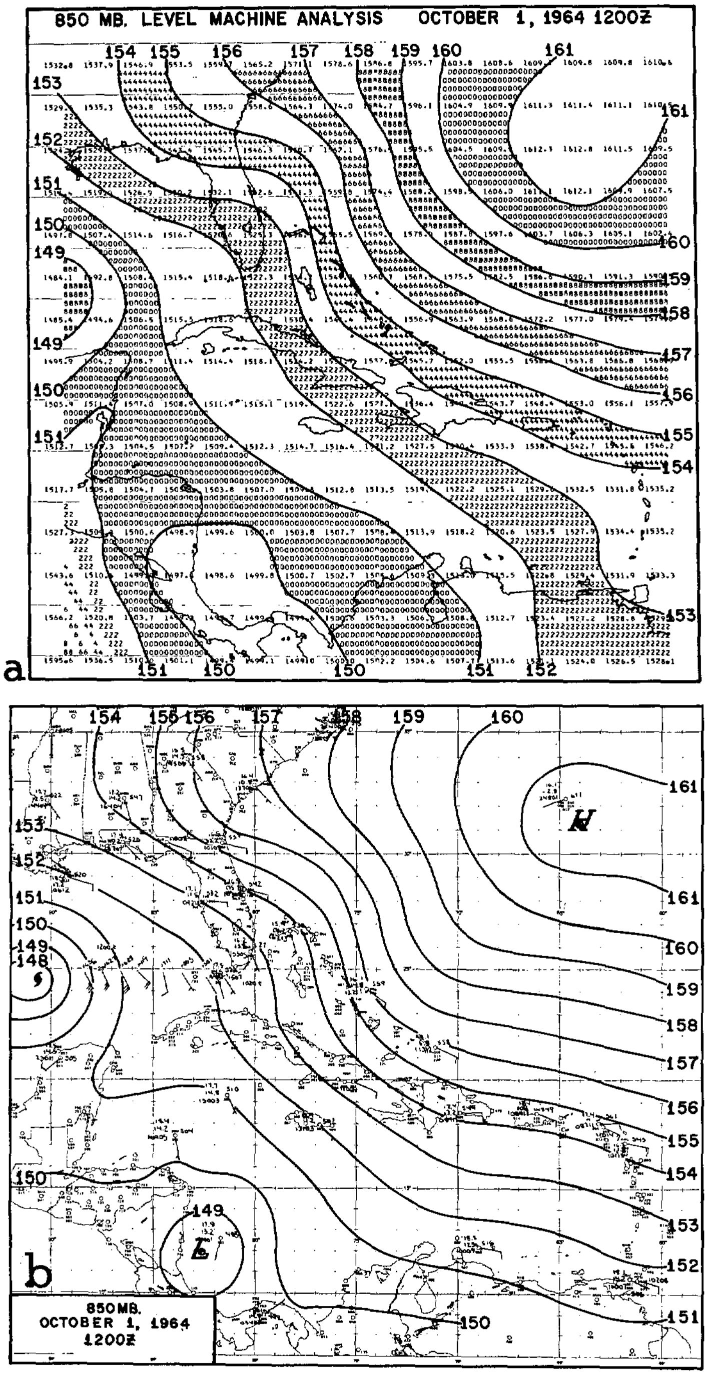


FIGURE 13.—850-mb. pressure-height surface, 1200 GMT, October 1, 1964. (a) Objective analysis. (b) Conventional analysis. Labeling as in figure 10.

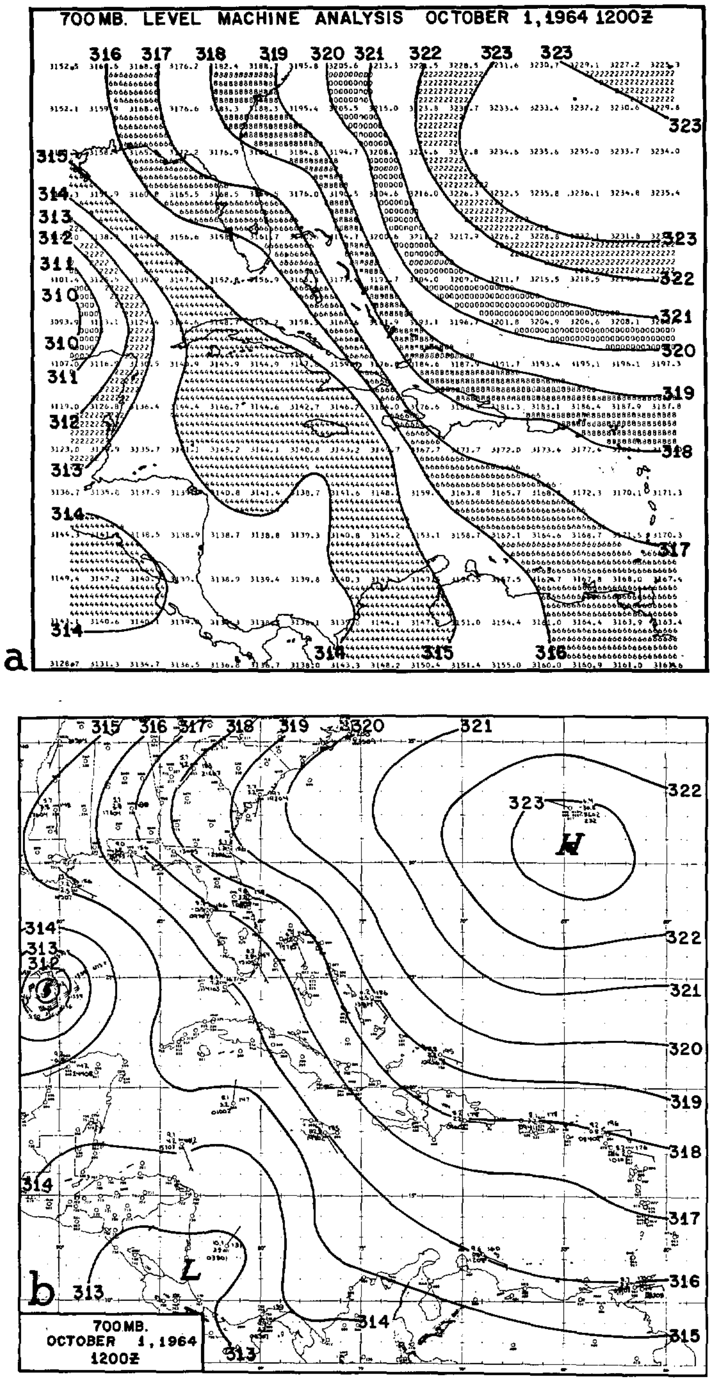


FIGURE 14.—700-mb. pressure-height surface, 1200 GMT, October 1, 1964. (a) Objective analysis. (b) Conventional analysis. Labeling as in figure 10.

TABLE 7.—*400-mb. pressure-height data for 1200* GMT, *September 30, 1964. See table 5 for explanation of symbols.*

STATION	OH	SH	FH	RES	AH	ARES	DD	FF
001	7551.2	7559.3	7561.2	-1.9	7560.5	-1.2	290	12
016	7644.8	7644.8	7645.4	-0.7	7644.5	0.2	90	12
063	7577.9	7596.5	7596.4	0.1	7598.2	-1.7	70	20
089	7574.7	7582.8	7585.0	-2.2	7580.8	2.0	140	13
201	7600.8	7586.6	7588.0	-1.4	7586.2	0.3	90	16
202	7590.9	7592.5	7592.1	0.3	7594.8	-2.3	80	26
206	7601.0	7609.6	7607.2	2.3	7613.2	-3.6	200	16
208	7598.0	7602.9	7606.6	-3.7	*	*	230	22
211	7619.2	7603.9	7603.2	0.8	7607.0	-3.0	140	13
214	7596.0	7595.4	7597.2	-1.8	7599.0	-3.5	222	13
221	7561.0	7581.2	7585.4	-4.2	7585.6	-4.4	230	27
222	7583.8	7580.2	7581.7	-1.5	*	*	200	10
226	7583.1	7563.4	7567.1	-3.7	7567.2	-3.8	230	37
232	7606.5	7584.8	7580.8	4.0	7581.0	3.8	220	21
235	7530.2	7534.1	7534.1	0.1	7532.6	1.6	240	32
240	7563.0	7551.0	7548.7	2.3	*	*	270	27
248	7498.2	7520.2	7524.3	-4.1	*	*	270	34
304	7592.5	7611.7	7612.9	-1.2	*	*	220	27
308	7577.0	7580.4	7578.6	1.8	*	*	230	47
311	7602.5	7579.8	7572.1	7.6	*	*	230	45
317	7571.5	7565.3	7566.9	-1.6	*	*	240	47
327	7469.2	7489.5	7491.2	-1.8	*	*	240	44
340	7475.9	7489.9	7486.4	3.5	*	*	260	25
384	7571.0	7569.6	7565.1	4.5	7572.0	-2.4	290	4
397	7525.5	7551.5	7556.6	-5.1	7554.3	-2.8	20	7
486	7615.7	7596.9	7585.5	11.4	7593.7	3.2	150	12
501	7591.6	7576.5	7573.5	3.0	7574.5	2.0	110	8
526	7589.9	7588.4	7592.5	-4.0	7590.0	-1.6	320	8
644	7608.5	7597.6	7599.0	-1.5	7596.4	1.1	220	1
794	7616.2	7611.0	7607.0	4.0	7616.2	-5.2	110	14
806	7558.2	7562.1	7561.6	0.5	7563.0	-0.8	60	3
861	7585.8	7578.2	7577.8	0.4	7578.0	0.2	340	10
866	7597.4	7580.3	7582.9	-2.6	7580.7	-0.4	350	14
897	7542.9	7578.3	7577.8	0.5	7578.2	0.1	320	6
967	7574.3	7575.0	7572.7	2.3	7575.5	-0.5	80	10
988	7568.7	7572.4	7578.1	-5.7	7574.4	-2.0	90	6
			36 STATIONS		26 STATIONS			
			RMSE=3.533 m.		RMSE=2.510 m.			

TABLE 8.—*250-mb. pressure-height data for 1200* GMT, *September 30, 1964. See table 5 for explanation of symbols.*

STATION	OH	SH	FH	RES	AH	ARES	DD	FF
001	10893.4	10904.8	10909.9	-5.1	10906.6	-1.8	70	10
016	10965.0	10965.0	10966.7	-1.7	10964.8	0.2	90	10
063	10939.2	10946.5	10948.8	-2.3	10948.5	-2.0	40	37
089	10922.9	10930.1	10931.7	-1.6	10924.7	5.5	170	22
201	10980.1	10960.4	10957.8	2.6	10961.6	-1.2	30	16
202	10963.9	10958.1	10955.5	2.5	10960.0	-1.9	30	23
206	10947.9	10960.5	10958.5	2.0	10964.9	-4.5	270	16
208	10922.4	10933.2	10937.3	-4.1	*	*	250	26
211	10992.7	10971.1	10968.9	2.2	10974.4	-3.4	310	8
221	10908.5	10933.0	10943.5	-10.5	10937.7	-4.7	240	35
222	10949.7	10940.9	10944.3	-3.4	*	*	310	23
226	10926.0	10905.8	10913.1	-7.3	10909.0	-3.2	240	40
232	10974.0	10946.7	10934.5	12.2	10947.4	-0.7	230	22
235	10849.1	10864.9	10863.7	1.2	10867.9	-3.0	250	58
240	10912.1	10901.4	10894.2	7.2	*	*	270	43
248	10812.0	10843.3	10854.0	-10.6	*	*	260	61
304	10924.1	10930.9	10931.4	-0.5	*	*	260	17
308	10909.6	10905.6	10907.2	-1.6	*	*	240	42
311	10937.3	10915.0	10906.5	8.5	*	*	240	47
317	10900.1	10893.1	10890.7	2.4	*	*	240	53
327	10766.7	10797.0	10799.2	-2.2	*	*	240	69
340	10750.0	10781.6	10775.5	6.1	*	*	250	56
384	10936.4	10933.0	10928.9	4.1	10936.5	-3.5	0	23
397	10858.2	10897.3	10911.1	-13.7	10902.0	-4.7	0	0
486	10993.5	10958.3	10938.1	20.2	10951.8	6.5	270	16
501	10956.8	10943.7	10934.1	9.5	10943.0	0.6	70	16
526	10925.0	10927.3	10937.6	-10.4	10930.0	-2.8	310	27
644	10998.9	10952.0	10952.3	-0.3	10958.2	-6.2	190	11
794	10983.6	10965.6	10961.5	4.1	10970.9	-5.3	350	11
806	10897.8	10903.7	10902.5	1.2	10904.0	-0.3	220	6
861	10918.5	10912.2	10910.6	1.6	10912.0	0.2	310	29
866	10942.2	10914.5	10916.7	-2.2	10913.4	1.2	340	19
897	10861.3	10915.1	10913.1	2.1	10915.0	0.1	290	21
967	10918.2	10920.1	10918.0	2.0	10921.6	-1.6	30	18
988	10911.0	10920.0	10928.0	-8.0	10924.8	-4.8	80	12
A23.0N 88.3W	10944.0	10951.2	10960.2	-9.0	10944.0	7.1	280	24
A24.5N 89.4W	10944.0	10957.4	10955.8	1.7	10948.5	8.9	30	46
A23.2N 89.6W	10944.0	10951.9	10954.4	-2.5	10946.6	5.3	280	19
A24.5N 88.5W	10944.0	10954.1	10961.2	-7.1	10946.0	8.1	100	42
			39 STATIONS		29 STATIONS			
			RMSE=6.674 m.		RMSE=4.226 m.			

TABLE 9.—*850-mb. pressure-height data for 1200* GMT, *October 1, 1964. See table 5 for explanation of symbols.*

STATION	OH	SH	FH	RES	AH	ARES	DD	FF
001	1488.4	1497.3	1500.0	-2.7	1498.9	-1.6	210	2
016	1610.8	1610.8	1611.6	-0.8	1610.9	-0.1	260	2
063	1529.8	1539.4	1540.6	-1.2	1534.8	4.7	170	26
089	1558.9	1554.8	1549.3	5.4	1554.6	0.2	120	22
118	1558.0	1552.3	1552.7	-0.4	1551.5	0.8	110	24
201	1523.2	1521.6	1521.7	-0.1	1519.1	2.5	160	2
202	1527.3	1526.3	1530.0	-3.7	1522.5	3.8	150	8
206	1556.5	1547.2	1546.5	0.7	1548.4	-1.2	100	16
208	1566.4	1563.2	1562.2	1.0	*	*	140	11
211	1532.0	1529.3	1530.7	-1.5	1529.5	-0.2	90	25
214	1535.0	1541.8	1539.3	2.5	1544.8	-3.0	110	16
221	1520.0	1535.1	1533.6	1.5	1537.5	-2.4	140	14
226	1546.6	1540.7	1543.7	-3.0	1543.6	-2.9	170	8
232	1520.3	1518.1	1515.4	2.7	1518.8	-0.7	110	22
235	1521.7	1528.0	1531.1	-3.1	1530.3	-2.3	150	8
240	1517.0	1518.3	1518.8	-0.5	*	*	90	15
248	1530.4	1524.8	1523.2	1.5	*	*	150	10
304	1574.7	1575.8	1576.9	-1.1	*	*	220	12
311	1558.3	1557.5	1554.0	3.5	*	*	140	8
367	1535.0	1527.6	1529.0	-1.3	1528.0	-0.4	101	17
384	1509.7	1513.0	1513.4	-0.3	1513.0	0.0	140	6
397	1502.1	1518.1	1517.6	0.5	1516.8	1.3	130	8
405	1535.0	1526.9	1526.0	0.9	*	*	120	19
486	1544.4	1538.6	1538.5	0.1	1537.0	1.6	90	22
501	1503.5	1506.6	1506.4	0.3	1507.5	-0.9	170	8
526	1548.5	1544.7	1548.5	-3.8	1544.6	0.0	110	20
644	1504.9	1497.6	1498.9	-1.3	1497.9	-0.3	230	27
794	1541.7	1538.6	1541.2	-2.5	1535.3	3.4	100	15
806	1498.8	1499.9	1497.6	2.3	1499.5	0.4	60	4
861	1545.2	1541.1	1542.8	-1.7	1544.9	-3.8	100	29
894	1535.0	1544.8	1547.7	-2.9	1548.6	-3.8	110	27
967	1535.6	1531.2	1530.8	0.4	1531.1	0.1	110	13
970	1535.0	1531.3	1532.7	-1.5	1531.3	-0.1	100	16
988	1516.3	1516.4	1514.6	1.7	1515.9	0.5	100	18
866	1560.7	1560.7	1548.4	12.3	1548.8	11.9	Missing	
			35 STATIONS		29 STATIONS			
			RMSE=2.954 m.		RMSE=3.024 m.			

TABLE 10.—*700-mb. pressure-height data for 1200* GMT, *October 1, 1964. See table 5 for explanation of symbols.*

STATION	OH	SH	FH	RES	AH	ARES	DD	FF
001	3130.5	3137.6	3139.4	-1.7	3138.5	-0.8	10	2
016	3231.5	3231.5	3232.0	-0.5	3231.6	-0.1	290	4
063	3141.5	3171.5	3172.9	-1.4	3169.1	2.4	160	21
089	3185.8	3185.9	3180.9	4.9	3185.1	0.8	140	28
118	3195.0	3188.9	3187.0	1.9	3188.8	0.1	110	11
201	3161.1	3153.4	3152.7	0.6	3153.2	0.1	140	8
202	3159.2	3160.0	3162.2	-2.2	3158.6	1.4	150	10
206	3186.2	3177.7	3179.8	-2.1	3179.2	-1.5	130	10
208	3197.0	3188.3	3187.7	0.6	*	*	200	10
211	3166.0	3166.5	3165.0	1.5	3166.3	0.2	100	12
214	3168.0	3170.7	3172.9	-2.2	3172.4	-1.7	132	9
221	3155.6	3163.6	3165.7	-2.1	3164.5	-0.9	160	10
222	3161.7	3154.0	3154.6	-0.6	*	*	80	6
226	3179.7	3166.6	3169.6	-2.9	3167.3	-0.6	160	10
232	3155.7	3149.6	3141.0	8.6	3149.1	0.5	120	15
235	3147.9	3150.5	3153.2	-2.7	3151.6	-1.1	170	8
240	3146.3	3140.3	3135.7	4.5	*	*	170	11
248	3146.3	3145.7	3147.1	-1.4	*	*	90	2
304	3199.5	3196.7	3198.2	-1.5	*	*	240	17
311	3182.8	3175.1	3169.4	5.7	*	*	220	14
384	3147.1	3145.9	3143.0	2.9	3146.6	-0.6	350	4
397	3124.9	3139.8	3147.0	-7.2	3142.1	-2.3	140	4
486	3178.0	3176.7	3175.4	1.4	3177.5	-0.8	90	14
501	3142.1	3140.4	3140.9	-0.5	3141.5	-1.1	150	14
526	3178.1	3178.2	3185.2	-6.9	3179.5	-1.3	90	22
644	3142.2	3120.5	3112.7	7.8	3109.6	10.9	250	14
794	3177.3	3173.3	3175.1	-1.9	3171.6	1.7	100	12
806	3138.7	3137.8	3136.5	1.3	3138.2	-0.4	70	14
861	3175.5	3175.0	3175.7	-0.7	3180.0	-5.0	100	21
967	3175.1	3166.8	3166.7	0.1	3166.5	0.3	70	13
970	3168.0	3166.3	3168.2	-1.9	3166.1	0.2	82	16
988	3159.6	3158.2	3155.5	2.7	3157.6	0.6	110	16
866	3195.3	3195.3	3181.9	13.4	3182.5	12.8	Missing	
A25.0N 86.1W	3127.0	3135.8	3135.7	0.1	3141.0	-5.2	135	20
A25.0N 88.2W	3103.0	3120.0	3122.4	-2.4	3125.7	-5.7	154	36
A24.5N 90.0W	3088.0	3094.4	3106.9	-12.5	3100.1	-5.7	150	62
			36 STATIONS		30 STATIONS			
			RMSE=4.510 m.		RMSE=3.783 m.			

TABLE 11.—*200-mb. pressure-height data for 1200* GMT, *October 1, 1964. See table 5 for explanation of symbols.*

STATION	OH	SH	FH	RES	AH	ARES	DD	FF
001	12391.4	12392.7	12384.0	8.6	12387.6	5.0	160	2
016	12372.2	12372.2	12371.8	0.4	12371.9	0.3	70	8
063	12373.2	12402.4	12411.2	-8.8	12401.8	0.6	30	29
089	12405.9	12400.0	12390.5	9.5	12395.9	4.1	180	7
118	12415.0	12400.7	12389.6	11.2	12398.9	1.8	350	37
201	12429.7	12429.6	12424.4	5.3	12429.9	-0.3	0	24
202	12434.9	12417.5	12421.2	-3.7	12420.0	-2.4	20	37
208	12385.0	12373.2	12372.6	0.7	*	*	300	45
211	12421.6	12440.4	12439.4	1.0	12443.0	-2.7	330	27
221	12380.0	12409.9	12417.8	-7.9	12415.4	-5.5	260	43
222	12438.7	12428.7	12429.4	-0.7	*	*	260	21
226	12393.9	12376.5	12374.0	2.5	12377.7	-1.3	250	47
232	12422.7	12419.7	12424.7	-5.1	12424.1	-4.4	230	37
235	12319.7	12340.1	12336.6	3.5	12350.2	-10.0	250	57
240	12398.2	12374.6	12372.8	1.8	*	**	230	49
248	12332.0	12320.8	12321.8	-1.0	*	*	240	61
304	12385.6	12359.5	12360.6	-1.2	*	*	270	63
311	12317.7	12336.1	12343.9	-7.8	*	*	260	67
384	12379.2	12380.5	12377.4	3.1	12381.5	-1.0	40	19
397	12283.2	12339.3	12355.8	-16.5	12349.6	-10.3	100	13
486	12393.2	12395.1	12392.2	2.9	12394.3	0.8	340	30
501	12390.5	12387.8	12390.3	-2.5	12387.5	0.2	40	31
526	12375.4	12377.7	12389.2	-11.6	12379.4	-1.7	320	20
794	12448.8	12419.8	12423.6	-3.9	12427.5	-7.7	340	34
806	12405.7	12400.1	12404.8	-4.6	12400.3	-0.2	200	16
861	12333.7	12371.1	12368.0	3.1	12369.3	1.8	310	33
866	12433.3	12373.4	12369.3	4.1	12371.7	1.7	340	33
967	12399.2	12392.5	12390.1	2.4	12393.4	-0.9	40	6
988	12411.8	12406.4	12406.8	-0.4	12406.2	0.2	340	8
206	12436.9	12436.9	12415.3	21.6	12427.6	9.3	Missing	

30 STATIONS 24 STATIONS

RMSE=7.185 m. RMSE=4.446 m.

TABLE 12.—*850-mb. pressure-height data for 1200* GMT, *September 11, 1961. See table 5 for explanation of symbols.*

STATION	OH	SH	FH	RES	AH	ARES	DD	FF
001	1505.6	1509.8	1511.2	-1.4	1511.2	-1.4	80	16
016	1563.5	1563.5	1564.5	-1.0	1563.7	-0.2	20	4
063	1546.9	1549.3	1548.8	0.5	1550.1	-0.8	60	11
089	1537.1	1541.4	1544.8	-3.4	1542.0	-0.6	190	4
118	1549.0	1547.4	1544.4	3.0	1546.5	1.0	130	9
201	1558.1	1543.4	1543.8	-0.4	1543.1	0.3	130	10
202	1544.4	1548.0	1546.9	1.1	1548.1	-0.2	90	10
206	1561.5	1560.1	1560.5	-0.4	1561.3	-1.2	110	9
208	1571.4	1571.1	1571.2	-0.1	*	*	100	7
211	1561.8	1550.2	1549.7	0.5	1550.7	-0.5	130	10
214	1540.0	1552.7	1554.2	-1.6	1554.1	-1.4	140	15
221	1543.5	1542.4	1542.4	-0.0	1543.4	-1.0	140	19
226	1550.5	1552.7	1552.9	-0.2	1553.5	-0.8	130	16
232	1502.7	1504.0	1504.6	-0.7	1509.1	-5.2	150	41
304	1560.1	1565.6	1565.8	-0.3	*	*	50	3
311	1570.1	1571.1	1570.5	0.6	*	*	120	12
325	1540.7	1541.5	1541.2	0.3	1539.9	1.6	190	3
355	1529.8	1533.9	1533.7	0.2	*	*	10	8
367	1540.0	1537.0	1539.1	-2.1	1538.0	-1.0	59	8
384	1540.9	1538.4	1535.1	3.3	1539.7	-1.3	150	10
397	1520.5	1535.0	1533.4	1.6	1535.3	-0.3	90	6
401	1540.0	1532.7	1533.5	-0.8	1532.6	0.0	90	18
403	1540.0	1533.4	1534.1	-0.6	1532.3	1.1	150	8
457	1540.0	1544.5	1542.8	1.6	1543.8	0.6	110	8
467	1564.4	1544.4	1542.9	1.5	1543.9	0.5	180	6
501	1521.5	1524.4	1527.8	-3.4	1525.9	-1.5	150	26
526	1540.6	1540.9	1543.3	-2.4	1541.4	-0.5	80	13
535	1540.0	1540.1	1542.8	-2.7	1540.3	-0.2	89	12
644	1497.8	1501.7	1501.1	0.6	1503.2	-1.5	160	20
720	1540.0	1523.0	1513.6	9.4	1518.9	4.1	120	4
794	1551.0	1555.6	1554.8	0.8	1557.2	-1.6	100	9
806	1503.5	1504.2	1502.0	2.3	1503.3	1.0	40	6
861	1530.0	1537.9	1537.2	0.8	1538.5	-0.5	90	10
866	1540.5	1540.1	1540.3	-0.3	1539.8	0.2	110	10
894	1540.0	1539.9	1539.9	-0.0	1539.9	0.0	109	10
897	1526.5	1535.8	1535.9	-0.1	1536.6	-0.8	100	14
967	1548.8	1543.3	1541.7	1.5	1541.0	2.3	130	16
988	1530.2	1535.3	1534.2	1.1	1535.4	-0.1	120	14

38 STATIONS 34 STATIONS

RMSE=2.155 m. RMSE=1.477 m.

TABLE 13.—*500-mb. pressure-height data for 1200* GMT, *September 11, 1961. See table 5 for explanation of symbols.*

STATION	OH	SH	FH	RES	AH	ARES	DD	FF
001	5848.0	5860.5	5858.8	1.7	5863.1	-2.6	120	16
016	5893.2	5893.2	5893.9	-0.7	5893.3	-0.1	10	4
063	5856.2	5872.6	5870.3	2.3	5872.0	0.6	30	7
089	5856.4	5865.9	5872.6	-6.6	5866.1	-0.1	270	8
118	5889.6	5887.0	5886.0	1.0	5887.6	-0.6	220	19
201	5898.2	5878.1	5876.5	1.6	5877.8	0.2	320	4
202	5866.6	5875.5	5873.2	2.3	5875.2	0.3	10	8
206	5882.3	5887.6	5889.2	-1.6	5889.1	-1.5	130	3
208	5899.3	5894.9	5895.8	-0.9	*	*	180	5
211	5891.7	5882.2	5881.5	0.6	5882.7	-0.5	70	8
221	5869.1	5884.1	5887.5	-3.4	5885.9	-1.8	130	10
222	6018.9	5978.5	5960.3	-1.8	*	*	80	23
226	5888.6	5888.5	5888.1	0.3	5889.5	-1.0	120	4
232	5867.0	5860.3	5861.3	-1.1	5864.6	-4.3	150	32
304	5887.4	5890.7	5892.6	-1.9	*	*	190	2
311	5899.0	5892.3	5889.9	2.3	*	*	200	6
325	5872.1	5878.7	5879.3	-0.6	5878.8	-0.1	20	6
355	5851.3	5860.0	5857.5	2.4	*	*	270	6
367	5887.0	5878.3	5880.1	-1.8	5878.3	-0.0	227	14
384	5877.8	5879.1	5880.9	-1.8	5879.7	-0.6	270	8
397	5865.4	5881.6	5880.2	1.3	5881.3	0.2	260	10
401	5887.0	5879.4	5883.6	-4.2	5879.8	-0.4	90	18
403	5887.0	5879.0	5881.4	-2.4	5879.1	-0.1	87	16
467	5913.8	5899.1	5892.1	7.0	5898.4	0.7	120	6
501	5880.9	5879.9	5881.2	-1.3	5880.3	-0.4	100	6
526	5888.7	5890.4	5893.3	-2.9	5892.7	-2.3	100	10
644	5880.5	5878.6	5876.3	2.3	5878.3	0.2	150	12
794	5878.0	5883.2	5880.0	3.2	5883.0	0.2	80	8
806	5853.2	5861.4	5865.1	-3.8	5865.3	-4.0	100	15
861	5873.4	5879.6	5881.1	-1.5	5880.6	-0.9	40	17
866	5890.7	5884.6	5886.8	-2.1	5886.3	-1.7	70	12
897	5864.8	5877.2	5878.7	-1.6	5877.9	-0.7	50	14
967	5882.6	5878.5	5872.4	6.1	5877.3	1.2	70	18
988	5877.6	5884.4	5886.4	-2.0	5885.0	-0.5	100	19

34 STATIONS 29 STATIONS

RMSE=2.808 m. RMSE=1.459 m.

TABLE 14.—*300-mb. pressure-height data for 1200* GMT, *September 11, 1961. See table 5 for explanation of symbols.*

STATION	OH	SH	FH	RES	AH	ARES	DD	FF
001	9639.5	9653.4	9655.2	-1.9	9656.4	-3.0	80	10
016	9649.8	9649.8	9650.5	-0.7	9650.0	-0.2	330	12
063	9620.9	9646.4	9642.2	4.2	9644.5	1.8	0	10
089	9628.7	9635.6	9638.5	-2.9	9633.4	2.2	340	8
118	9655.8	9657.1	9659.0	-1.9	9658.3	-1.2	230	32
201	9687.5	9663.4	9662.4	1.0	9663.8	-0.4	10	17
202	9650.9	9655.5	9652.7	2.7	9655.9	-0.5	0	18
206	9656.2	9663.3	9667.7	-4.5	9663.2	0.0	350	14
208	9668.3	9668.8	9665.1	3.7	*	*	110	17
211	9680.5	9671.1	9669.7	1.4	9670.8	0.3	10	30
221	9655.8	9678.2	9686.0	-7.8	9682.5	-4.3	270	27
222	9813.5	9774.4	9776.8	-2.4	*	*	90	21
226	9682.6	9659.1	9664.1	-4.9	9659.4	-0.2	270	31
232	9714.3	9708.5	9705.1	3.4	9705.8	2.7	320	24
304	9658.0	9663.2	9669.3	-6.1	*	*	40	12
311	9650.4	9657.6	9647.2	10.4	*	*	170	10
325	9660.8	9666.0	9668.2	-2.2	9665.6	0.4	20	26
355	9617.3	9633.0	9630.5	2.5	*	*	340	10
384	9663.5	9663.4	9666.7	-3.4	9664.2	-0.8	330	17
397	9653.4	9659.7	9659.7	0.0	9657.9	1.8	250	22
403	9688.0	9682.1	9688.9	-6.7	9683.2	-1.0	81	19
467	9696.5	9683.7	9676.2	7.5	9683.8	-0.0	220	12
501	9690.8	9680.4	9676.4	3.9	9678.4	2.0	10	18
526	9680.5	9682.2	9686.2	-4.0	9684.4	-2.2	0	5
644	9714.8	9707.6	9710.8	-3.2	9708.1	-0.5	20	2
794	9657.7	9658.3	9658.5	-0.2	9656.7	1.6	350	14
806	9656.1	9660.0	9662.0	-2.0	9662.8	-2.8	110	6
861	9670.3	9680.5	9680.0	0.5	9680.7	-0.2	20	2
866	9701.4	9681.5	9684.0	-2.5	9681.5	-0.0	350	3
897	9670.2	9678.9	9679.0	-0.1	9680.2	-1.3	60	10
967	9689.4	9684.0	9678.5	5.4	9682.9	1.1	80	14
988	9689.6	9687.3	9688.9	-1.6	9688.4	-1.0	90	12

32 STATIONS 27 STATIONS

RMSE=4.081 m. RMSE=1.640 m.

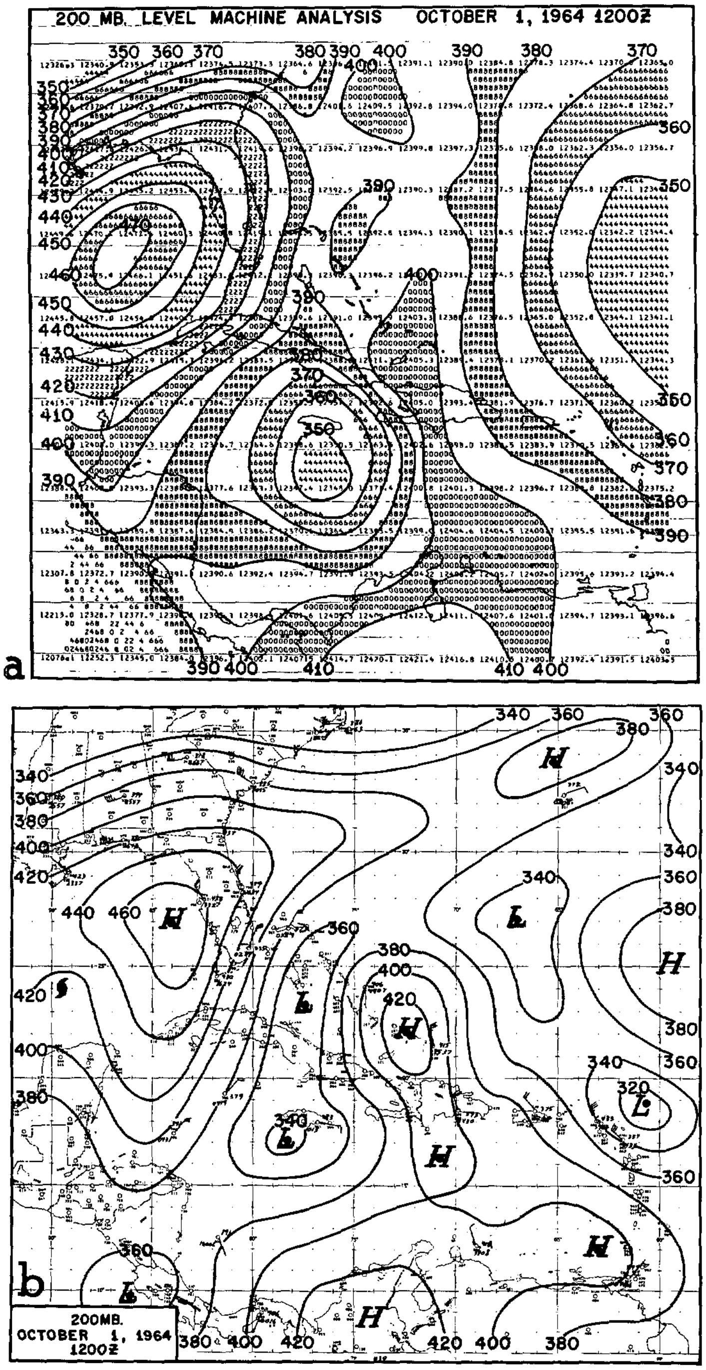


FIGURE 15.—200-mb. pressure-height surface, 1200 GMT, October 1, 1964. (a) Objective analysis. (b) Conventional analysis. All isopleths are labeled in units of meters, the label being the three low-order digits of the value. Grid-point labeling as in figure 9.

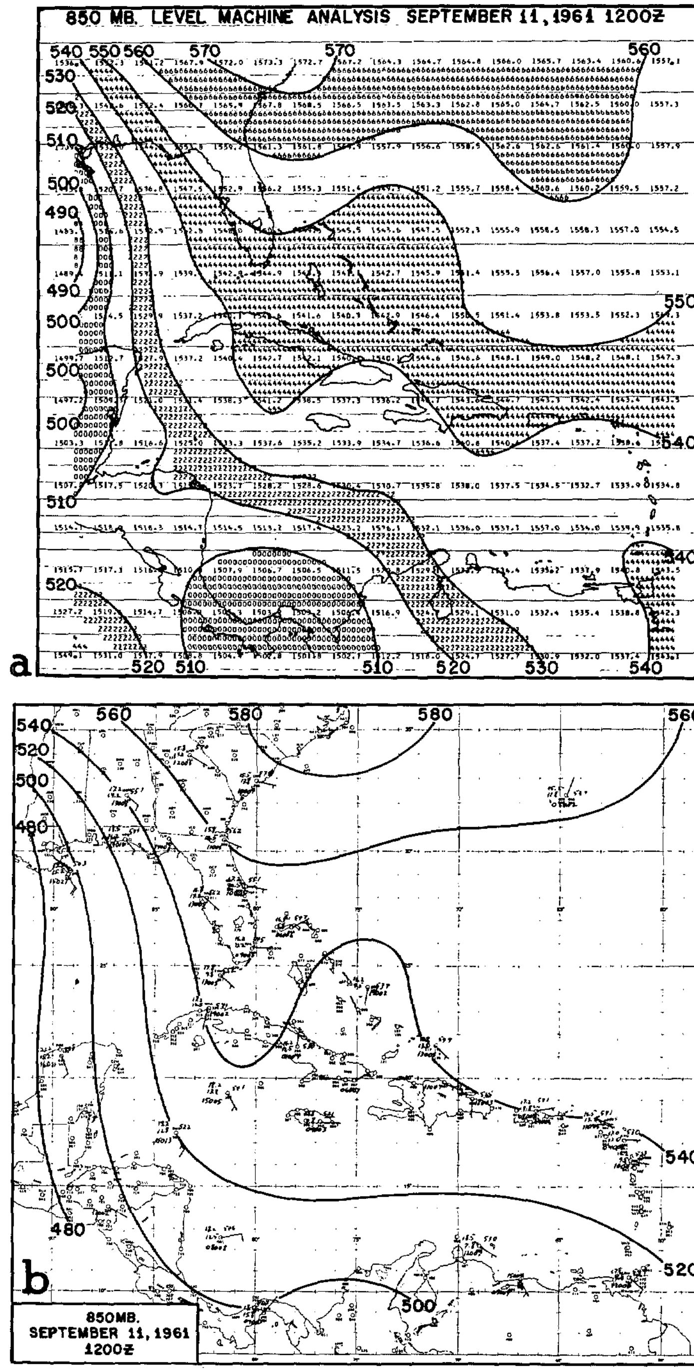


FIGURE 16.—850-mb. pressure-height surface, 1200 GMT, September 11, 1961. (a) Objective analysis. (b) Conventional analysis. Labeling as in figure 15.

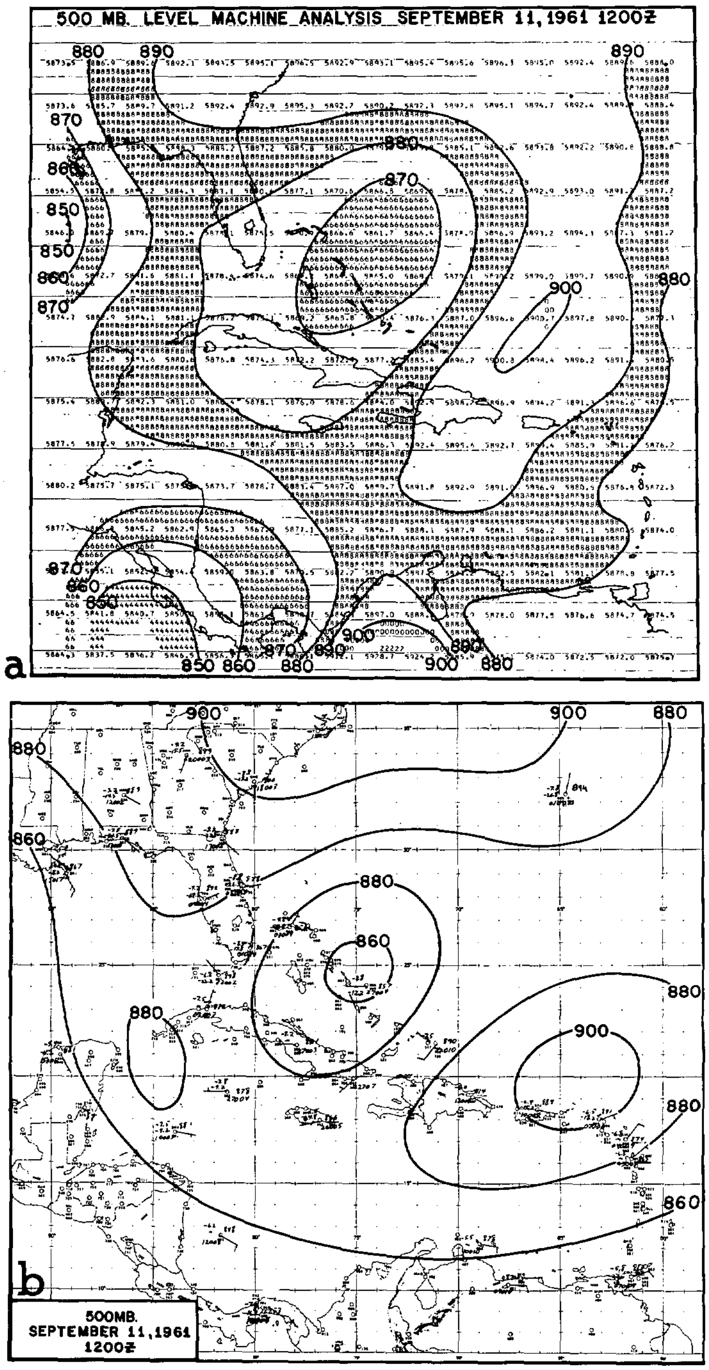


FIGURE 17.—500-mb. pressure-height surface, 1200 GMT, September 11, 1961. (a) Objective analysis. (b) Conventional analysis. Labeling as in figure 15.

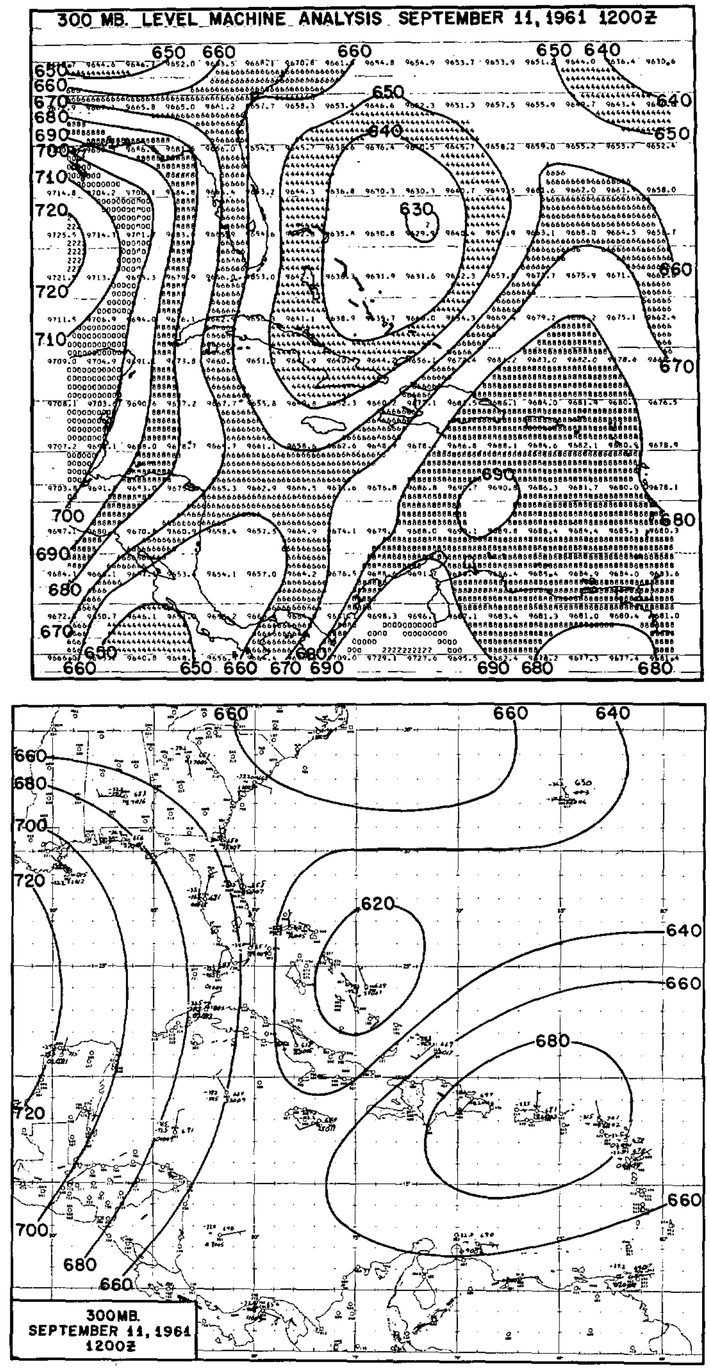


FIGURE 18.—300-mb. pressure-height surface, 1200 GMT, September 11, 1961. (a) Objective analysis. (b) Conventional analysis. Labeling as in figure 15.

HEIGHT ANALYSES FOR 1200 GMT, OCTOBER 1, 1964

850 mb. (*fig. 13, table 9*). There is exceptionally good agreement in the analyses, especially in the Gulf of Mexico-Florida peninsula areas. Again, the extreme southwestern corner of the objective analysis reflects the complete lack of data in this area.

700 mb. (*fig. 14, table 10*). As with the 850-mb. analyses, the 700-mb. analyses agree remarkably well. The objective analysis in the Gulf area is based on data from Merida (644), Burrwood (232), and three RECCO reports east of the storm, which explains the height gradients in the region of hurricane Hilda.

200 mb. (*fig. 15, table 11*). Considering the complexity of the pattern in the height field, along with the paucity of data (24 reporting stations within the grid area), the objectively produced analysis gives a good presentation of the synoptic features. The spurious high values (OA) between Charleston (208) and Bermuda (016) are a result of the Hatteras (304) data being extrapolated southward. The analysis (SA) south of Bermuda (016) is based on continuity. The OA analysis in this region is flat because of the lack of data.

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850 mb. (*fig. 16, table 12*). The major synoptic-scale features are well established in the objective analysis. There is good indication of the presence of hurricane Carla in the western Gulf of Mexico. The trough over Cuba and the Bahamas is positioned correctly but with somewhat less amplitude than that given on the conventional analysis. In response to the data at Santo Domingo (485) and San Juan (526), the OA has placed a weak trough over Puerto Rico and indicated troughing northeastward from Panama.

500 mb. (*fig. 17, table 13*). The objective analysis shows the Low centered over San Salvador (089), but with less amplitude than that analyzed subjectively. The SA analysis of the High centered over the Leeward Islands is questionable. The OA treats it as a ridge extending out from the High centered northwest of Bermuda (016). On the OA, the presence of hurricane Carla in the Gulf of Mexico is indicated by low height values to the southwest of Burrwood (232). Again, the extreme southwest (OA) is doubtful because of the data void.

300 mb. (*fig. 18, table 14*). As with the 500-mb. objective analysis, the Low over the Bahamas is positioned correctly but with less amplitude than indicated by the subjective analysis. In general, the objective analysis has good positioning of the major synoptic features and gives slightly more detail than the subjective analysis. The OA analysis over northern South America is a reflection of the data from Bogota, Colombia (222) (see table 14), and may be questionable.

5. CONCLUSION

The objective analysis technique described in this report gives pressure-height analyses which are comparable to the conventional subjective analyses of an experienced analyst. The method does not require the specification of an initial guess at the grid points. A first guess is generated with an interpolation polynomial which is derived from the actual height and wind reports. The two principal methods of objective analysis discussed in the literature are utilized: (1) the least-squares fitting of the data to obtain an interpolation function, and (2) the iterative-correction process. In addition, a systematic method for extending the analysis into sparse data regions is employed.

Prior to the determination of the interpolation polynomial, the height data at stations are adjusted (smoothed) so that the height gradients between contiguous stations are consistent with the reported winds. The adjusted heights are then extrapolated into data voids by using the reported winds to approximate geostrophic height gradients. This provides a distribution of heights which is relatively uniform over the region of analysis and which, therefore, facilitates the derivation of the interpolation polynomial. The polynomial describes the height data reasonably well. Subsequent iterative-correction modifications of the Cressman type serve to enhance the representativeness of the objective analysis. Only in extreme data voids (regions having a centroid extremely distant from data reporting stations) are the resulting analyses non-representative.

On the basis of the experiments carried out during the development of the analysis method described in this report, it is concluded that a significant improvement in low latitude analysis, objective or subjective, can be effected only by significantly expanding the existing data-reporting network.

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